CALIFORNIA ENERGY COMMISSION

CALIFORNIA BOARD OF CORRECTIONS

ENERGY EFFICIENCY DESIGN GUIDE FOR CALIFORNIA DETENTION FACILITIES

Guidebook

APRIL 2001
P400-01-010

Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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Disclaimer

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Preface to Second Edition

This energy efficiency design guide was first published in 1990, a time of great activity in design and construction of adult detention facilities. Now, 11 years later, there is a similar level of activity in the development and expansion of juvenile detention facilities. This revision incorporates changes and design considerations appropriate for juvenile and adult facilities. The information has been updated to include advancements in energy efficient building technology. Several new topics have been added, and some topics have been eliminated because they have become standard practice and are no longer relevant. The target audience remains unchanged: architects, engineers, lighting designers, local government planning staff, and others involved in the planning and design of new facilities.

The new topics are:

- High albedo roof and wall surfaces
- Variable speed pumping
- Chilled water plant design
- High efficiency cooling tower
- High efficiency packaged equipment
- Duct sealing and insulation
- High efficiency transformers
- Commissioning and maintenance considerations

Three new appendices have been added. Appendix A contains a sample scope of work that includes energy efficiency. Appendix B contains references for energy efficiency information. Appendix C contains acronyms and terms commonly used in this design guide.

Acknowledgements

Eley Associates of San Francisco prepared this design guide under contract to the California Energy Commission. This guide was prepared in cooperation with the California Board of Corrections. The authors at Eley Associates are Erik Kolderup, PE; Aditi Raychoudhury; and Jeff Stein. The California Energy Commission staff involved in the development, review and editing of this guide include: Merry Bronson, Ray Darby, PE, Gary Flamm, Al Garcia, Don Kazama, PE, Virginia Lew, Daryl Mills, Mazi Shirakh, PE, Mike Sloss and Ram Verma, PE. The Energy Commission and Eley Associates are grateful for the comments and suggestions provided by the following: Toni Hafey, Dwight Hoertch, Doug Holien, Len Silvey and Michael Houghtby, California Board of Corrections; Harry Franey, California Department of Corrections, Matt Muniz, PE, Alameda County; Donald Cervantes, ACS Contracting; Shuen Low, Gayner Engineers; Tavi Dragos, PE, and Shulamit Rabinovich, PE, Jacobs Engineering; Peter Kuhn, PE, Kuhn and Kuhn; Patrick Sullivan, Patrick Sullivan Associates; Robert Veerkamp, Placer County; Chuck Boxwell, RNL Design; Michael Crumbly, Sacramento County; Steve Keeter, San Joaquin County; Mary Calderwood-Chiechi, City of Santa Ana; Jan Johnson, Southern California Edison; Dave Weiss, Southwest County Detention Facility; Lloyd Finley, Tulare County; David Inger, Ventura County; Joe Bodnar, West Valley Detention Center; and Richard Cardoza, West Valley Juvenile Hall.

Further Information

For information on detention facilities construction grant funding, security, fire and life safety plan review, contact the California Board of Corrections at (916) 445-5073 or its website: www.bdcorr.ca.gov.

For information on energy programs for public buildings and detention facilities contact the California Energy Commission, Energy Efficiency Division, at (916) 654-4008 or its website: www.energy.ca.gov/efficiency.

This guide can also be downloaded from both the California Board of Corrections and the California Energy Commission websites.

1. Energy Efficiency in Detention Facilities

Numerous energy efficiency opportunities exist in the design of detention facilities. Local governments can take advantage of these opportunities to keep energy demand and cost low without affecting facility operation.

Often, cost-effective efficiency measures can be omitted due to lack of easily accessible information during the planning and design phase. This design guide was developed to cover that information gap.

This design guide will be useful to architects, engineers, project managers, and local government planning staff, in the design of new detention facilities or retrofits, upgrades and expansions of existing facilities.

Measures included in this design guide will:

- Channel money that would otherwise be spent on wasted energy back into the operating budget of the facility;
- Increase inmate and staff comfort;
- Conserve energy resources;
- Reduce the future operating cost and the need to retrofit the facility to increase energy efficiency;
- May cost more but any additional costs will be recaptured over the life of the facility due to lower facility operating cost.

The recommendations in this guide will achieve energy savings without compromising security, safety or the work environment in detention facilities. All concepts have been used in other detention facilities and are based on commercially available technologies.

Savings Potential

Energy costs in California detention facilities range between 3 and 8 percent of total operating costs. These percentages may seem small, but amount to $10,000 per year for the smallest facilities and more than $1,000,000 per year for the largest facilities. It is also one of the few costs that can be significantly decreased without reducing staff or compromising the quality of the operation.

This guide contains recommendations that can save about 40 percent of the energy cost of the detention facility (Figure 1). For a 96-bed facility with 100,000 square feet, the annual energy cost for an efficient facility would be about $180,000, versus $300,000 for a standard facility. Savings are $120,000 per year.

Construction Cost versus Life-Cycle Cost

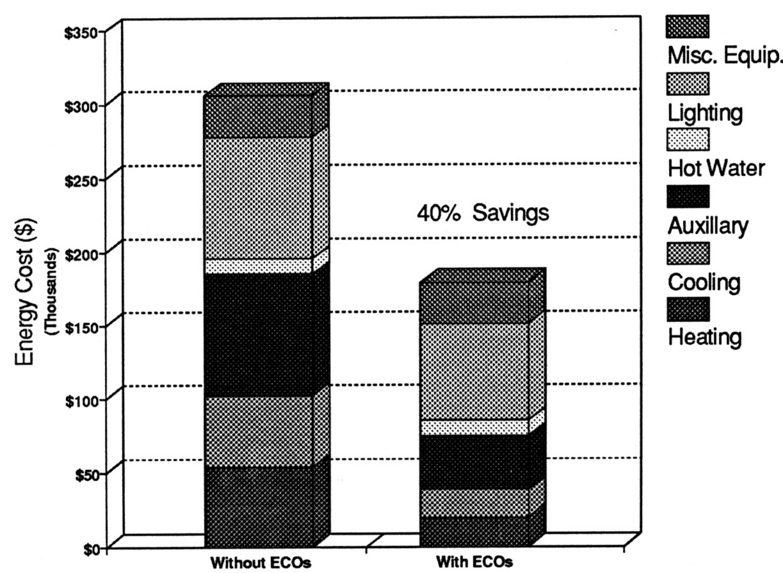


Figure 1 Potential Energy Savings

Miscellaneous equipment includes computers, control systems and other office equipment. Auxiliary equipment includes pumps and heat rejection equipment.

The first costs of construction represent only about 11 percent of the life-cycle cost of a typical facility (Figure 2). Construction cost is a one-time investment while operating costs must be paid each year over the life of the facility. Therefore, while construction costs of energy-efficient design features may be higher than conventional design, annual operating costs are reduced, rapidly compensating for the increased construction cost. Life cycle cost should guide capital expenditure decisions and funding policy should support energy efficient design.

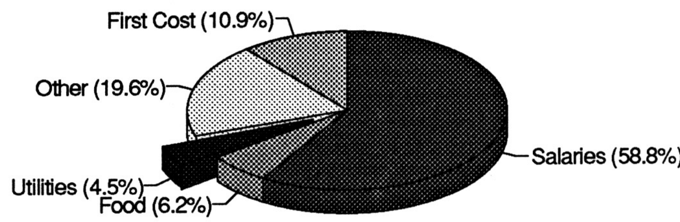


Figure 2 Life-Cycle Costs

Plan Ahead for Greater Benefits

Opportunities for energy efficiency rapidly diminish as the design process progresses (Figure 3).

The schematic design phase offers the best opportunity to select energy-efficient envelope, lighting and mechanical systems with the lowest life-cycle cost. Retrofitting after construction can be much more expensive than paying the costs up front. The first step is to increase the capital budget to account for energy efficiency measures.

Construction managers and planning personnel should consider energy efficiency when they first select the architect and engineer design team.

Design teams for most detention facilities should be

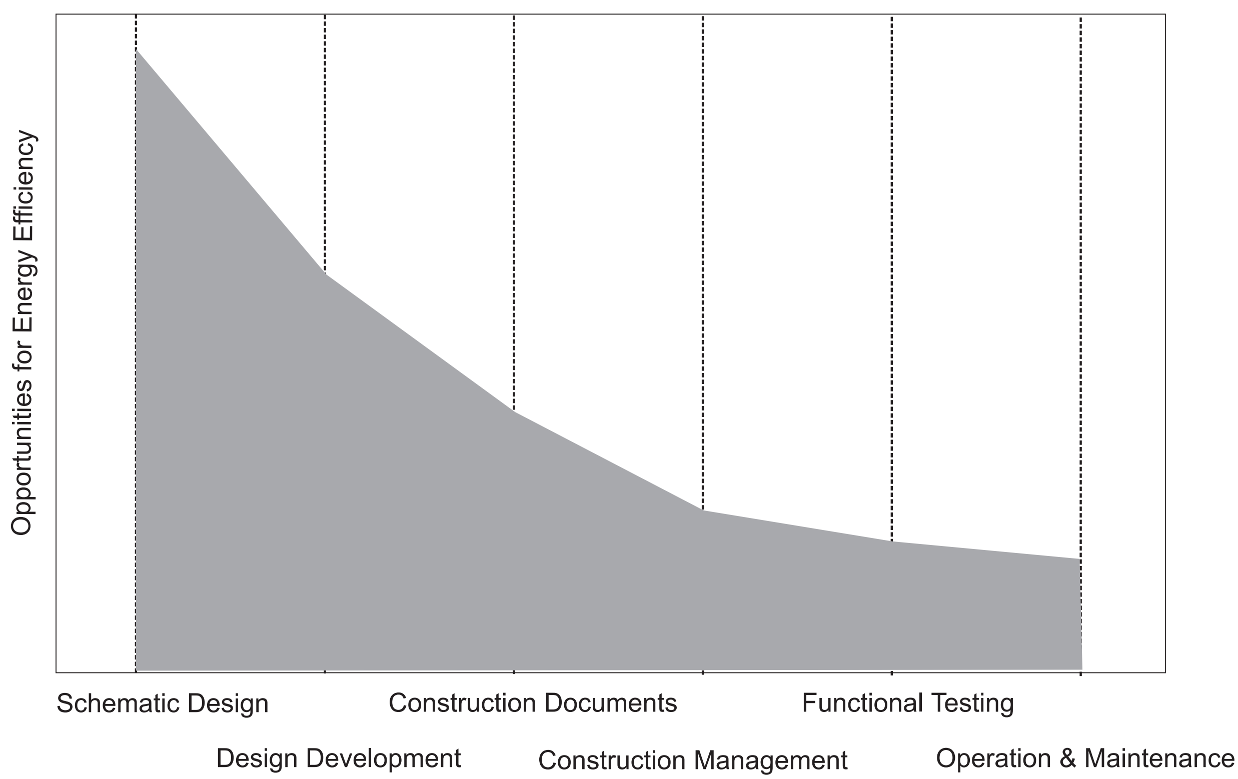


Figure 3 Energy Savings Opportunities in the Design Process

multi-disciplinary. Expertise is required not only in the design of the building envelope, but also in lighting and mechanical systems.

The scope of work for the design team should include identification, evaluation, and life cycle cost analysis for energy saving measures. Detention facility design must consider cost-effective future growth and expansion without compromising the use of higher efficiency equipment and systems. Appendix A contains a sample scope of work for the design team

Current Energy Standards

The Code of Regulations requires that the design of local detention facilities must comply with the Title 24 Nonresidential Building Energy Efficiency Standards and provisions shall be made to maintain a comfortable environment. The Title 24 Nonresidential Building Standards apply in their entirety to non-secure areas (i.e. office and administrative). Those requirements cover:

- Building envelope components
- Lighting systems
- Heating, ventilating and air conditioning systems
- Water heating systems

In security or living areas, only the heating, ventilating and air-conditioning requirements of the Appliance Standards, Title 20, apply.

The base case model used to estimate the savings presented in this design guide assumed that all areas meet the provisions of Title 24, Energy Efficiency Standards. The recommendations offered here go beyond the minimum requirements.

Project Management Considerations

The project manager plays a critical role in the development of an energy efficient facility. This section describes several ideas that will help ensure successful implementation of cost-effective efficiency measures.

Life Cycle Cost Requirement

Ensure that budgeting decisions will be made based on life-cycle cost rather than lowest first cost. Include a statement in the project program requiring that design decisions be based on life-cycle cost.

Life Cycle Cost Requirement in Design Team Scope of Work

Require that the design team evaluate energy efficiency options based on life-cycle cost.

Consider Performance Based Fees for Designers and/or Contractors.

Performance based fees are a new concept in which part of the designer or contractor payment is based on the actual operating efficiency of the facility. The idea is to overcome the traditional problem where the design and construction team have little incentive to create an optimal lifecycle cost design since they do not have to pay the utility bills.

Advances in measuring and monitoring systems allow the actual performance of the building to be recorded. The performance can be compared to targets set during the project planning process. Typically these targets will be based on an energy simulation of a baseline design.

There are several ways to structure a performance-based contract, and the best choice depends on the type of project. For design/build projects, the general contractor may be held responsible for meeting the performance target. In other cases, the design team, commissioning agent or contractor may have part of their fees linked to performance.

After the first or second year of building occupancy, the designer or contractor receives a reward if the building beats the performance target. A penalty may be imposed if performance falls short of the goal.

Make Commissioning a Formal Element of the Project

Commissioning is the process of ensuring that the intent of the project program is properly reflected in the design and that the design intent is properly executed during construction and operation. Commissioning tasks start at the very beginning and continue throughout the project even into the occupancy period. Experience has shown that many energy efficient designs do not achieve intended savings without the oversight and testing included in a commissioning process.

The project manager should consider including an independent commissioning agent in the early planning process. A commissioning plan should be developed during schematic design and updated at each project phase.

Chapter 6 contains additional information on commissioning.

Seek Utility Incentives and Other Assistance

Contact utilities, state energy agency, and energy consultants during the earliest phases of the project to find out if technical and/or financial assistance is available to support energy efficiency measures.

Include Operating and Maintenance Personnel in Planning and Design Process

Experience has shown that many operating problems can be eliminated by following the advice of facility maintenance personnel at the beginning of the planning process. In addition, early involvement provides training opportunities and improves efficient system operation.

Require Energy Analysis and Integrated Design

Require the use of energy analysis tools during the design phase to optimize performance. These tools are usually necessary to determine the benefits of integrated design. For example, the design team can evaluate tradeoffs between envelope improvements and heating, ventilating and air conditioning (HVAC) sizing. Improvements in the building envelope can potentially reduce the overall project cost while also improving efficiency.

Resources

This design guide contains appendices, which provide additional information and resources to help you in facility design and management.

2. How to Use the Design Guide

This design guide contains a collection of cost-effective energy efficiency opportunities (EEOs) developed specifically for California detention facilities. The EEOs are organized by design discipline.

- Chapter 3 discusses opportunities associated with the building envelope.
- Chapter 4 discusses lighting system opportunities.
- Chapter 5 discusses mechanical system measures.
- Chapter 6 discusses other equipment and operation considerations.
- Chapter 7 contains technical documentation of the assumptions and methods used to calculate energy savings and determine cost effectiveness.

Chapters 3, 4 and 5 are intended for the architect, electrical engineer/lighting designer and mechanical engineer, respectively.

Within each chapter, the EEOs are organized according to their position in the design process. Those EEOs that should be considered very early in the design process are presented first, while those that can still be considered later in the process are presented last.
Each chapter begins with a general section describing the overall importance of the element of building design (envelope, lighting or mechanical system).

A matrix at the beginning of each chapter summarizes all of the recommendations and their applicability to typical areas in detention facilities (living areas, kitchen/laundry, and administration). The matrix rates each EEO as "cost effective" or "not applicable." A measure is rated cost effective if the energy savings over a ten-year period are greater than the incremental cost of the measure.

Cost effectiveness can also be defined by the life-cycle cost (LCC), which has also been calculated for each EEO. The LCC of a measure is the first cost of the measure plus the annual operating costs, discounted to 2000 dollars. The economic assumptions are described in Chapter 7.

Each EEO begins on a new page and includes three sections.

- The recommendation and its applicability for spaces within detention facilities. This is followed by a more detailed description of the EEO.
- The cost of the EEO, the expected cost savings, and the cost effectiveness of the investment.
- Design guidelines to enable the EEO to be included in the design. This section explains how the designer can use the information presented, and describes how to avoid misapplications.

Chapter 6 is intended for both the design team and the facility owners and operators. This chapter contains information for both the electrical designer (transformers) and the facility owner and operator (maintenance and commissioning)

Building Area Descriptions

Most EEOs are evaluated for living and administrative spaces. Anticipated operating costs can vary greatly depending on which space within the facility is being analyzed.

Living Area

Living areas include medium and maximum-security housing areas and dormitory-type housing arrangements. All analysis is based on a 15,000 square feet cluster, consisting of three, two-story pods with 32 beds each, totaling 96 occupants per housing unit.

Living areas need to be considered separately because heating and cooling loads are different than offices and administration areas. The HVAC system is operated continuously in living areas, which make related EEOs cost-effective from an energy perspective. For living areas, outside air ventilation is much higher, internal heat gain is lower and solar gain is lower because glass area is limited.

Administration

The custody staff and other employees occupy administration areas. The administration facilities are assumed to be conditioned continuously, although occupancy and lighting levels are assumed to be reduced during the graveyard shift. All analysis is based on a building of 15,000 square feet. Window area is about 30 percent of the exterior wall.

Central Plant

The energy savings and costs for central plant EEOs are based on a facility with roughly equal amount of living and administration area. The chilled water and hot water loads are combined for the two space types to analyze central plant EEOs.

Accounting for Different Sized Facilities

Since costs and savings are listed by square foot of floor area, a designer can scale the results to calculate the cost effectiveness of EEOs for different-sized facilities.

Climate Regions

Energy savings are calculated for five climate regions in California (Figure 4). The energy savings for each region are based on the climate conditions for the following representative cities:

- Coast. Santa Maria represents the coastal regions of California. This climate region is appropriate for all areas of the state where the weather is influenced primarily by ocean weather patterns.
- South. Riverside represents the south inland coastal conditions of southern California and is appropriate for much of Orange and Riverside Counties.
- Valley. Fresno, representing the Central Valley, generally has hot

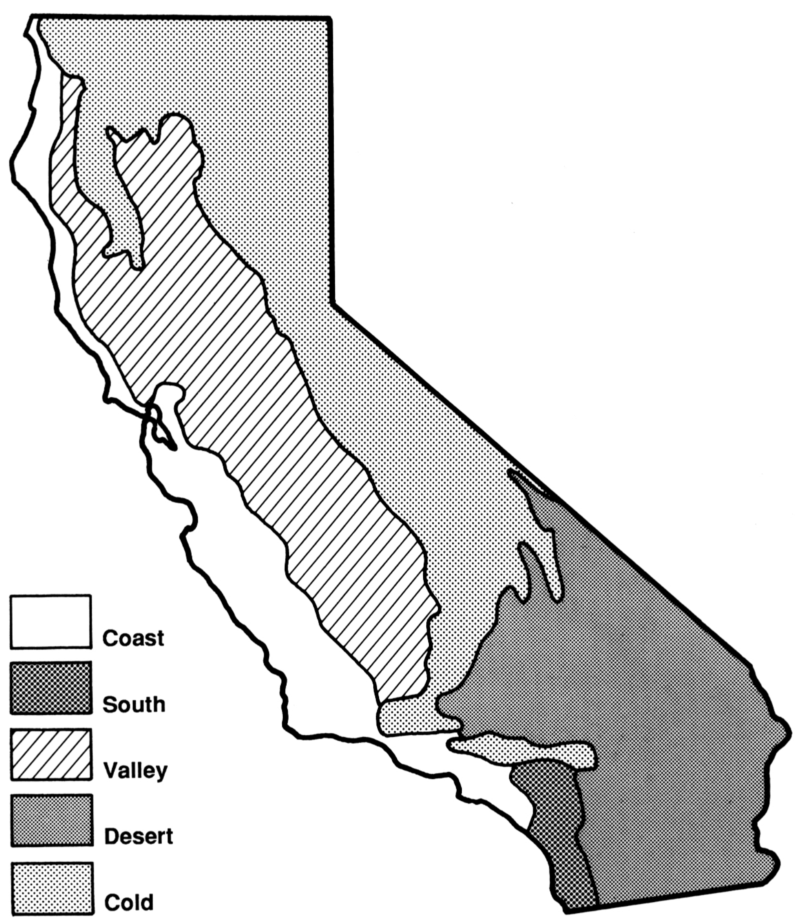


Figure 4 California Climate Regions

days and cool nights.
- Desert. China Lake represents the desert areas of the state.
- Cold. Mount Shasta represents the cold and generally mountainous regions of the state. The climate is characterized by cold but sunny winter days.

Other locations in the state may have weather conditions different from the representative cities. Chapter 7 contains a summary of weather conditions for the representative cities so that comparisons can be made and the appropriateness of the representative cities validated.

While weather conditions for a specific site may be different from the representative cities, the guidelines may still be applicable.

More detailed information on the building model and assumptions used for each building area are discussed in Chapter 7.

Presentation of Cost Effectiveness Data

Savings for most measures are based on simulation results using DOE2.1E. The computer model was run for each of the climate regions using weather tapes that give temperature, wind speed, and humidity information for the specific cities. The weather tapes provide representative conditions for each hour of a typical year.

There are typically two ways of evaluating the cost effectiveness of investments in energy efficiency: life cycle cost and simple payback.

Life-cycle cost is the total cost of the EEOs, considering both the initial construction investment as well as the annual operating costs. The method for calculating life-cycle cost is presented in Chapter 7.

Simple payback is a measure of how long it takes to recoup the incremental investment for an EEOs, defined as the increased material and installation costs divided by the annual energy savings. Simple payback periods are included for most alternatives proposed in this guide. A simple payback of less than 10 years is considered cost-effective.

For most EEOs, there is a table that provides the incremental cost, the annual energy cost savings, the payback (in years), and the life cycle cost savings. The life cycle cost savings account for both first cost increases and savings in operating costs. Any assumptions that may influence the data are included as footnotes in the table.

3. Building Envelope

Energy efficiency is one of the many considerations in the design of the envelope of detention facilities. The principal purpose is to detain persons convicted or awaiting trial on criminal or civil charges. The recommendations contained in this chapter do not compromise this purpose.

Many recommendations will improve the comfort of both staff and occupants. Detention facilities are usually constructed of masonry, concrete or other durable materials capable of providing a secure surrounding for occupants. These types of construction are difficult to insulate without compromising the durability of construction. Exterior insulation should be applied only in areas where occupants have no access. Otherwise, insulation should be placed in the cavities.

Structural requirements for earthquakes require that almost all the cavities within masonry construction be reinforced and grouted. This leaves little or no space for insulation. In this case, exterior insulation should be considered, special insulation inserts can be used, or special wall constructions should be pursued where space for both reinforcing and insulation is provided.

The building envelope serves many functions important to energy efficiency, allowing natural light and, in some cases, ventilation to penetrate the building. The envelope reduces heat losses when it is cold and heat gains when it is hot.

It also allows occupants some contact with the out-of-doors through windows and skylights. The state building code, Title 24, Part 6, requires natural light in the living areas.

There are many general energy efficiency strategies used by designers of detention facilities. Although these common envelope design strategies are not specifically evaluated in the guide, designers should continue to use them. Some of these common techniques are:

- Use at least R-19 roof insulation for the living areas and at least R-13 roof insulation for all other areas of the detention facility. Up to R-38 insulation is often cost-effective in the mountain, desert and Central Valley areas.
- Use at least R-13 in all framed wall construction.
- Consider orientation in site planning and placement of glazing.
- Weather-strip windows, doors and other openings and employ other means to reduce outside air infiltration.

Additional energy efficiency opportunities (EEOs) are evaluated in subsequent sections of this chapter. These are listed in the following matrix that indicates their applicability to the typical building areas.

Table 1 identifies the recommended building envelope measures and their cost-effectiveness. These building envelope systems are discussed in the next sections.

Table 1 Building Envelope Applicability Matrix

EEO	Page #	Recommendation	Living Areas	Administ ration/ Office	Kitchen
Double Envelope Construction	11	Consider a double envelope design for exterior walls in colder climate areas of the state	N.C.	N.A.	N.A.
Integrally Insulated Masonry Construction	13	Use integrally insulated masonry construction when it is desirable to have a durable surface on both sides of a masonry wall.	N.C.	N.A.	N.A.
Exterior Insulation Finish Systems (EIFS)	17	Use an exterior insulation finish system (EIFS) when occupants do not have access to the outside of the masonry wall.	$$$	$$$	N.A.
High Albedo Roof and Wall Surfaces	19	Use reflective surfaces in climates where cooling energy costs exceed heating costs to significantly reduce cooling load.	$$$	$$$	$$$
Exterior Shading Devices	22	Use overhangs and sidefins to shade glazing on east, south and west facades of administration and office buildings.	N.A.	$$$	N.A.
Skylights	24	Use skylights and automatic lighting controls in the dayrooms of living areas.	$$$	N.A.	$$$
Glazing	27	Use double glazing with a low solar heat gain coefficient in all climates	N.A.	$$$	N.A.

Key:
$$$ Cost Effective
N.C. Not cost-effective
N.A. Not applicable

Double Envelope Construction

Comment:
If a double envelope design is used for the living areas, then avoid direct conditioning of the space between the envelopes.

One method of constructing the housing areas of detention facilities is to build two envelopes. The inner envelope is constructed of masonry and concrete and is designed to provide a secure environment for the detention of occupants. The second envelope provides the thermal and moisture barrier from nature's elements. The space between the two envelopes provides a convenient place for the mechanical systems necessary to detention facilities.

Some economies in the construction of the inner envelope can be made because the shapes are simple and the mechanical shafts are eliminated. All the plumbing, heating and air conditioning ducts are located between the inner and outer envelope. Mechanical access is improved and economies are possible for plumbing and mechanical systems.

From the jail managers' perspective, this design has the advantage of not requiring maintenance personnel to enter the secure housing areas during routine maintenance.

There are a few potential disadvantages to the double envelope design. Additional building area is created that must have a lighting system, leading to increased lighting energy. If the space is conditioned, then no energy savings occur.

Cost Effectiveness

Due to high construction cost, this measure is not cost-effective based solely on energy savings. The estimated cost premium for the example living area is more than $234,000. This estimate assumes building a double envelope instead of a single concrete or masonry wall.

Ease of maintenance and mechanical system economies might justify the investment. The mechanical cost reductions are not accounted for in the estimate of the increased cost.

Double envelope construction is a high cost, long payback and no life cycle cost savings option. Unless absolutely needed for maintenance or other reasons, more cost-effective EEOs described in this guide should be considered first before investing in double envelope design.

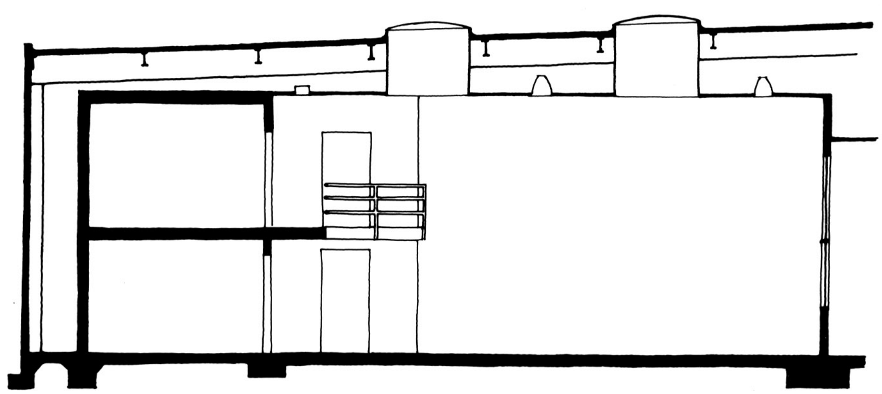


Figure 5 Double Envelope Construction

Design Guidelines

Many methods are available to construct the outer envelope. A common method uses a metal frame covered with gypsum sheathing. The sheathing is covered with rigid foam insulation board and this layer is covered with a weather surface (see the section on Exterior Insulation Finish Systems).

Do not locate temperature-sensitive equipment in the space between the envelopes. If conditioning is required for electrical or telephone equipment, then isolate that conditioned space from the rest of the service area, which should remain unconditioned.

In order to meet the requirements of the state fire marshal, the unconditioned space between the two envelopes must be of nonflammable construction. Gypsum sheathing meets this requirement, but structural framing must be sprayed with a fire-resistant material.

> A portion of the Rio Consumnes Correctional Facility in Sacramento County is a double envelope design where the outer envelope is a metal-framed building with an exterior insulation finish system. The interior envelope is concrete masonry. This design was chosen for ease of maintenance access. The space between the envelopes is conditioned; therefore, energy savings are minimal.

Integrally Insulated Masonry Construction

Comment:
Use integrally insulated masonry construction for exterior walls when it is desirable to have a durable surface on both sides of a masonry wall.

Masonry construction can be integrally insulated in two ways. One method is to use insulation inserts that leave space in the cavity for grouting and steel reinforcing (Figure 6). A second way is to provide a second cavity in addition to the one that must be reinforced to strengthen the building (Figure 7).

Integral insulation is recommended in cases where occupants have access to both sides of the wall; for instance, walls that separate outdoor recreation areas from housing areas. Durable surfaces are maintained on both sides of the wall, unlike applying exterior insulation (see next EEO).

In most cases, the insulating value is compromised by "thermal bridges" created by the concrete webbing in the masonry unit. Therefore, the effective R-value is lower than that of the insulation on its own (Table 2).

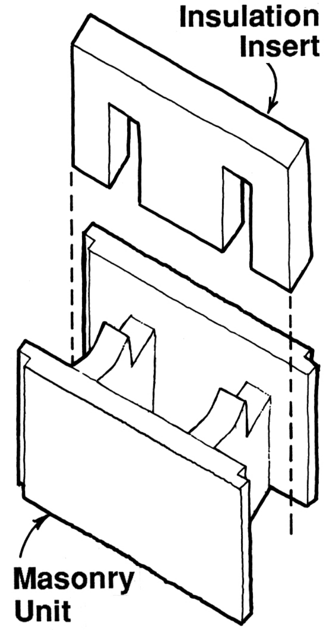


Figure 6 Masonry Unit with Insulation Insert

Cost Effectiveness

Energy savings are most significant for the living areas since they require space conditioning continuously and there are few internal gains from lights and equipment to offset heating loads. Integrally insulated masonry construction is not as cost effective for office or administration areas.

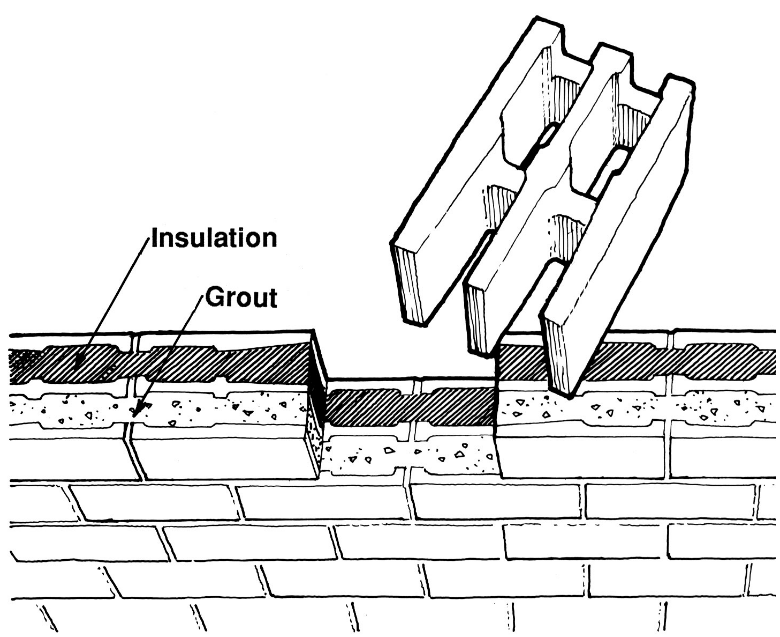


Figure 7 Masonry Wall with Second Cavity for Insulation

Annual energy savings range from $0.04 to $0.10 per square foot in living areas. Due to the relatively high cost premium of $2 to $3 per square foot, integral insulation is difficult to justify based on energy savings alone. However, there is the benefit of improved comfort, especially in very cold or very hot climates. In addition, heating and cooling equipment can be somewhat smaller and less expensive. Table 3 summarizes the cost-effectiveness of integrally insulated masonry

Table 2 Typical Thermal Performance of Integrally Insulated Masonry

Product Type		Effective U-factor Btu/(hr-ft²-°F)	Effective R-factor (hr-ft²-°F)/Btu
8 inch, fully grouted	Uninsulated	0.65	1.5
8 inch, partially grouted	Uninsulated	0.52	1.9
	Insulated	0.40	2.5
8 inch, ungrouted	Uninsulated	0.45	2.2
	Insulated	0.25	4.0

Source*: Energy Calculations and Data*, Concrete Masonry Association of California and Nevada, 1986.
Assumes 115 lbs/ft^3 concrete density.
U-factor and R-factor include boundary air layer insulating value, R-0.68 inside and R-0.17 outside.

construction in various areas of the state.

An alternative to consider in climates where the cooling costs exceed the heating costs is to use light-colored wall surfaces. This approach improves comfort and reduces system size resulting in a lower cost. High albedo roof and wall surfaces are discussed later in this guide.

Design Guidelines

Several masonry systems on the market are capable of providing the double cavity construction. One system employs a specially designed masonry unit with an inner and an outer cavity. The inner cavity is reinforced and grouted to provide the strength necessary for seismic design loads. The outer cavity is then filled with foamed in-place insulation. This proprietary system is offered under the trade name "SolarStone."

Another system has a large single cavity with a foam insulation insert applied in the factory. The remaining space in the cavity is reinforced and grouted. This system is known as "Korfil." The masonry units should be installed with the insulation on the exterior.

Insulation is not continuous in either of the systems and this effect was accounted for in the analysis of the energy savings. The insulated cavity within the wall was assumed to have an R-value of about 3.0. This is considerably less than the R-value of the insulation by itself.

It is not advisable to specify proprietary products when alternative products are available. Design professionals and construction managers should use specifications that allow either of the integrally insulating techniques to be used, since both are proprietary.

Occupant comfort, rather than cost effectiveness, may be the main reason for insulating masonry walls.

Comfort depends not only on air temperature, but also on the radiant temperature of the surfaces that surround a person. Uninsulated masonry walls are colder than the air temperature during heating conditions and warmer than the air temperature during cooling conditions.

When the mean radiant temperature is colder than the air temperature, the air temperature must be increased to maintain comfort. In summer, the opposite is true.

On cold days, the indoor temperature set points may have to be raised to maintain acceptable comfort in rooms with uninsulated masonry walls. Similarly, on hot days, the setpoint for air conditioning may have to be lowered to maintain comfort. The rule-of-thumb is one degree of air temperature for one degree of mean radiant temperature. For example, if the mean radiant temperature is 80°F, the thermostat should be set at

The San Joaquin County Sheriff's Operation Center and Jail Complex at French Camp uses the Korfil insulated concrete system, which employs factory-installed rigid insulation inserts in the concrete block cavities.

76°F to maintain comfort at 78°F.

Raising the indoor temperature significantly increases the energy use for heating and vice versa for cooling. While this effect is understood, computer simulation techniques are incapable of calculating the mean radiant temperature and adjusting the air temperature setpoint. The energy savings shown on the previous page do not account for this effect. If considered, the savings from insulating the walls would be greater.

Figures 8 and 9 show exterior wall temperature and mean radiant temperature in the cells with uninsulated masonry walls. Figure 8 is of a hot day in Fresno. Figure 9 is of a cold day in Mount Shasta.

Since mean radiant temperature changes depending on the position of the occupant in the space, the effect could be much greater for occupants positioned near the exterior wall.

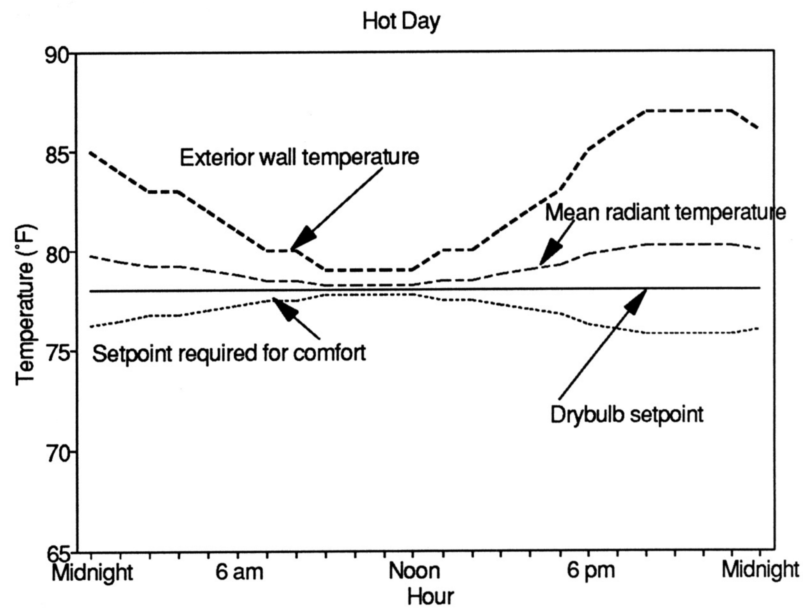


Figure 8 Setpoint Required for Comfort on Hot Day, Fresno, Uninsulated Masonry

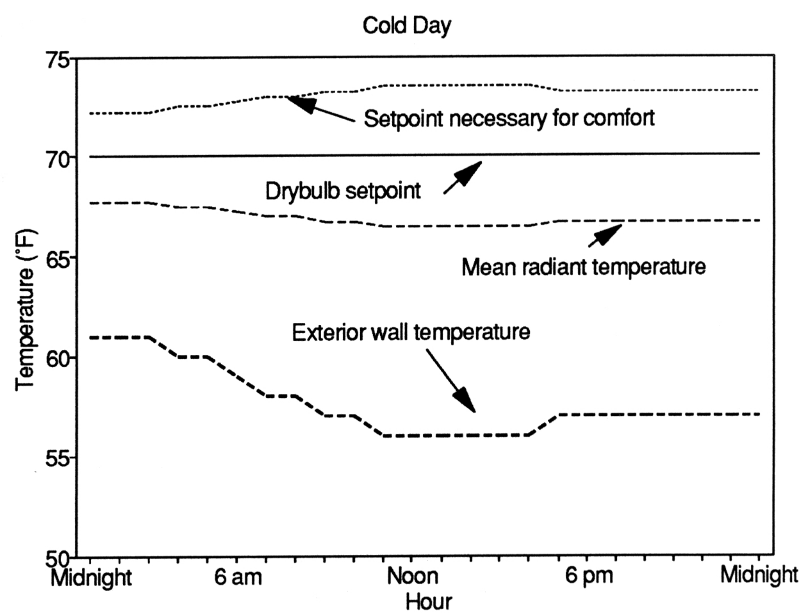


Figure 9 Setpoint Required for Comfort on Cold Day, Mount Shasta, Uninsulated Masonry

Table 3 Integrally Insulated Masonry

Climate	First Cost Premium ($/ft^2)	Annual Energy Savings ($/ft^2)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft^2)
Living				
Coast	2.72	0.04	67.5	neg.
South	2.72	0.07	40.5	neg.
Valley	2.72	0.08	35.9	neg.
Desert	2.72	0.10	28.5	neg.
Cold	2.72	0.10	26.3	neg.

Exterior Insulation Finish Systems (EIFS)

Comment:
Use an exterior insulation finish system in cold or hot climates for living areas when occupants do not have access to the outside of the masonry wall.

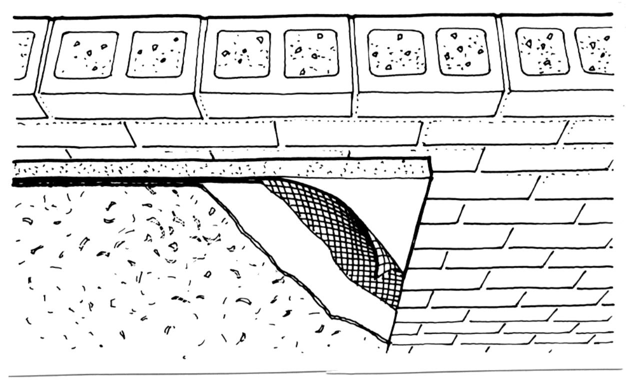


Figure 10 Exterior Insulation Finish System

Exterior masonry insulation provides a continuous insulating barrier for masonry walls but must be protected from physical damage. This system is often referred to as exterior insulation finish system or EIFS (Figure 10).

Two inches of insulation are recommended for living areas. One inch is recommended for offices and administration buildings with exterior masonry construction, particularly in colder regions.

Cost Effectiveness

Depending on climate, annual energy cost savings range from $0.11 to $0.24 per square foot for living areas within detention facilities. Savings are more significant for these areas because of the continuous operation of the HVAC system. Savings are less for administration and office areas except in cold regions.

The cost premium over an uninsulated masonry wall is about $7.00 per square foot of wall area for one inch of insulation and about $8.00 per square foot for two inches of insulation. The average cost per square foot of floor area is about $3.70, with simple payback period of 13 to 24 years. Table 4 summarizes the cost-effectiveness of EIFS for various climate areas of the state.

Just as with integrally insulated masonry, an EIFS wall provides greater comfort in addition to the energy savings.

EIFS do not require painting, which may result in additional operating cost savings compared to exterior wall systems that must be painted every five to ten years.

The economic analysis indicates that EIFS is not as cost-effective as other EEOs. However, it is the most cost-effective wall insulation option for masonry. Aside from energy savings, insulation can increase comfort for the occupants as discussed in the previous sections.

Southwest County Detention Facility in Riverside County has an EIFS on the exterior wall of the pods. They report no maintenance problems with this system.

The Rio Consumnes Correctional Facility in Sacramento County uses an EIFS (Dryvit) for a recent 448-bed addition on an 8-inch concrete masonry wall to match the original facility.

Design Guidelines

Rigid foam insulation is secured to the masonry wall either mechanically or with an adhesive. The insulation layer is continuous and provides a better thermal barrier than the integral masonry insulation method discussed previously.

A hard weather surface is applied to the insulation. The weather surface consists of a fiberglass reinforcing mesh

Table 4 Exterior Masonry Insulation

Climate	First Cost Premium ($/ft²)	Annual Energy Savings ($/ft²)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)
Living				
Coast	3.73	0.15	24.3	neg.
South	3.73	0.19	19.4	neg.
Valley	3.73	0.23	16.0	neg.
Desert	3.73	0.26	14.6	neg.
Cold	3.73	0.28	13.1	neg.

and a Portland cement mixture forming a rigid outer skin. Other products form a more flexible protective coat such as a polymer-based or polymer-modified weather finish. Polymer-modified finish coats are recommended because they offer higher impact resistance than polymer-based coats.

Exterior insulation should be installed by trained applicators. In fact, some manufacturers will not offer a warranty unless trained applicators are used. Problems that can occur from faulty installation include improper lapping of the reinforcing mesh and incorrectly applied sealants that allow water to penetrate the system.

It is important that a minimum thickness of 3/32 to 5/32 inch be specified for the base coat (weather coat) for sufficient weather resistance.

Fire ratings are not affected by EIFS. The material burns but does not contribute to the flame spread.

High Albedo Roof and Wall Surfaces

Recommendation:
Use reflective exterior roof and wall surfaces in climates where cooling energy costs exceed heating costs to significantly reduce cooling load.

A high albedo (reflectance) surface reflects the majority of solar heat that strikes a roof or wall. A typical roof surface such as a medium-colored mineral cap sheet may exceed 150°F on a sunny day, while a reflective roof can be more than 50°F cooler. Therefore, much less heat conducts through the roof, cooling loads are lower, and occupants feel more comfortable (Figure 11).

Two surface properties are important: reflectance and emissivity. Having a high reflectance means a material reflects the majority of solar heat. A reflectance of 0.75 or greater is desirable. For a roof or wall, a high emissivity surface will radiate more heat than a low emissivity surface, and the roof or wall temperature will remain lower. Surface emissivity should also be at least 0.75.

The U.S. Environmental Protection Agency sponsors an "Energy Star" roofing program. To qualify, a roof material must have a reflectance of at least 0.65 (for flat and low-slope roofs). Another organization, the Cool Roof Rating Council, is working to develop a standardized rating system for comparing reflective roof performance.

Cost Effectiveness

Many options for high albedo surfaces are cost free because products such as wall paint or roof membranes are offered in a range of colors including white. In addition, the reduced cooling loads may allow selection of smaller HVAC equipment and reduce overall project costs.

Some roof coatings will add between $0.50 and $1.50 per square foot of roof area to the construction cost compared to a typical membrane.

Table 5 shows that annual savings range from $0.03 to $0.08 per square foot of floor area. Roof savings are greater than wall savings in administrative areas because the framed walls are already insulated. Wall savings are more important in living areas especially when applied to uninsulated masonry, where a high albedo surface provides the additional benefit of improved summer comfort for occupants close to the wall.

Savings will increase if the roof or wall is poorly insulated or the HVAC system is inefficient.

Reflective surfaces also reduce peak cooling loads, saving money on air conditioning equipment. In climates where cooling energy costs exceed heating costs, using a reflective roof instead of roof insulation can significantly lower cooling

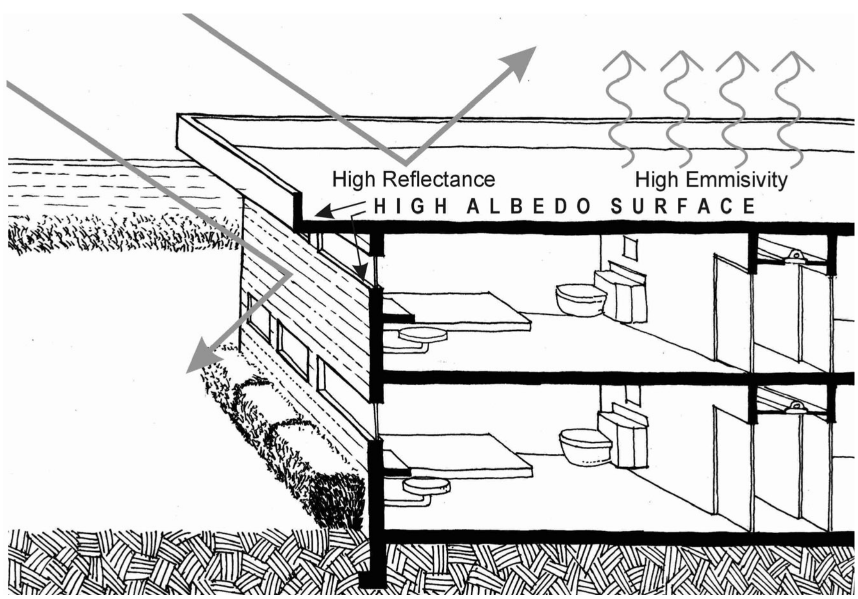


Figure 11 High Albedo Roof and Wall Surfaces

energy use. During the hot day, the reflective roof lowers the building temperature and at night, when the ambient temperature is mild, a cool roof with less insulation will transfer more heat to the outside environment.

Reflective roof surfaces can also lower capital cost of the project by reducing insulation requirements.

Design Guidelines

Apply a reflective coating to unshaded walls, especially west-facing facades. This reflective surface is especially important on uninsulated masonry because it helps eliminate interior comfort problems on summer afternoons and evenings. White paint is effective for walls; special products are not required.

There are several options for high-albedo roof surfaces including white liquid-applied coatings, white single-ply membranes, and white painted metal. Manufacturers should be able to supply reflectance and emmissivity data.

Note that aluminized liquid coatings that are often used on roofs are not as effective as white coatings. The same is true for unpainted metal. These metallic surfaces have a low emissivity. Therefore, they remain warmer when exposed to sunlight. Painted metal, regardless of color, remains cooler than unfinished metal.

White surfaces will lose some effectiveness if they become dirty, but periodic cleaning will restore much of the reflectivity. The designer should consider the facility's environment when deciding on using a high-albedo approach. For example, if the facility borders a farm that generates dust, then other measures such as insulation may be more appropriate to control heat gain.

Table 5 High Albedo Roof and Wall Surfaces

Climate	First Cost Premium ($/ft²)	Annual Energy Savings ($/ft²)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)
Living Area/Reflective Roof				
Coast	0.00	0.009	0.0	0.09
South	0.00	0.029	0.0	0.29
Valley	0.00	0.034	0.0	0.34
Desert	0.00	0.027	0.0	0.27
Cold	0.00	0.017	0.0	0.17
Living Area/Reflective Wall				
Coast	0.00	0.000	0.0	0.00
South	0.00	0.044	0.0	0.44
Valley	0.00	0.046	0.0	0.46
Desert	0.00	0.026	0.0	0.26
Cold	0.00	0.012	0.0	0.12
Living Area/Reflective Roof and Wall				
Coast	0.00	-0.003	0.0	neg.
South	0.00	0.070	0.0	0.70
Valley	0.00	0.078	0.0	0.78
Desert	0.00	0.050	0.0	0.50
Cold	0.00	0.024	0.0	0.24
Admin Area/Reflective Roof				
Coast	0.00	0.018	0.0	0.18
South	0.00	0.033	0.0	0.33
Valley	0.00	0.036	0.0	0.36
Desert	0.00	0.029	0.0	0.29
Cold	0.00	0.023	0.0	0.23
Admin Area/Reflective Wall				
Coast	0.00	0.013	0.0	0.13
South	0.00	0.019	0.0	0.19
Valley	0.00	0.017	0.0	0.17
Desert	0.00	0.015	0.0	0.15
Cold	0.00	0.012	0.0	0.12
Admin Area/Reflective Roof and Wall				
Coast	0.00	0.031	0.0	0.31
South	0.00	0.053	0.0	0.53
Valley	0.00	0.054	0.0	0.54
Desert	0.00	0.044	0.0	0.44
Cold	0.00	0.035	0.0	0.35

Assumptions

1) Results per square foot of total floor area, which is greater than actual roof area.
2) Assumes the white surface improves absortivity from a base case of 80% to 40%.
3) White surface available at no extra cost.
4) Does not account for potentially longer roof life.
5) Does not include any costs for roof cleaning or maintenance.

Exterior Shading Devices

Recommendation:
Use overhangs and sidefins to shade glazing on the east, south and west facades of administration and office buildings.

Fixed shading devices, such as overhangs and sidefins, reduce solar gains by preventing direct sunlight from entering the building (Figures 12 and 13). When direct sunlight is blocked, then glazing materials with a higher visible light transmission can be used without creating glare or discomfort problems.

Cost Effectiveness

Large overhangs can reduce annual energy cost by $500 for a typical office or administration building. Estimating the cost premium is more difficult since overhangs can be built of almost any material using almost any construction technique.

Besides reducing energy costs, fixed shading devices can create more comfortable environments and reduce glare in work areas.

Energy savings associated with overhangs depend on a number of factors including orientation, shading device dimensions, window dimensions and the solar optical properties of the glazing (solar heat gain coefficient (SHGC) and visible light transmittance). These glazing properties are discussed in the Skylight Section.

The principal factor is the ratio of projection of the overhang to the distance from the bottom of the window to the bottom of the overhang. This ratio, known as the projection factor (PF), is often used as a measure to evaluate overhangs.

Figure 14 shows the annual energy cost as a function of the size of an overhang. The small overhang has a PF of 0.25 indicating that the overhang is about one fourth the height of the window. The medium overhang has a PF of 0.50 and the large overhang has a PF of 1.00.

Design Guidelines

When overhangs and/or sidefins shade windows, the glazing can usually be modified. In general, clear glass with overhangs is better for daylighting purposes than tinted glass without overhangs.

Reflective glass with overhangs should not be considered because the overhangs would offer little additional benefit. Clear glass is recommended with overhangs.

When overhangs shade a portion of a window (part of the window in sun and part in shade), heat strengthened or tempered glass may be needed to withstand the thermal stresses created by this situation.

Sidefins can be used alone or in combination with overhangs. When used alone, they are useful mainly on east and west facades.

Sunscreens can also be used to provide exterior shade. Some manufacturers claim their products block up to 87 percent of solar heat gains. An equal or larger amount of daylight will also be blocked. Sunscreens may increase maintenance cost and distort views from windows.

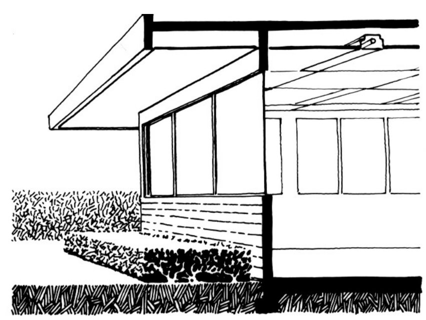


Figure 12 Window with Overhang

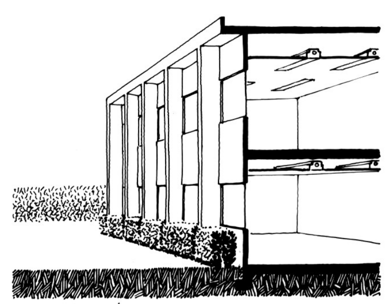


Figure 13 Window with Sidefins

Sunscreens are often constructed from a weather-resistant fiber mesh or metal screen stretched over a metal frame. Sunscreens fit into the window opening, just like an insect screen. When specifying sunscreens, it is important to maintain operability of the window and the screen where required for fire exiting. In addition, indicate the material, color and equivalent SHGC of the sunscreen.

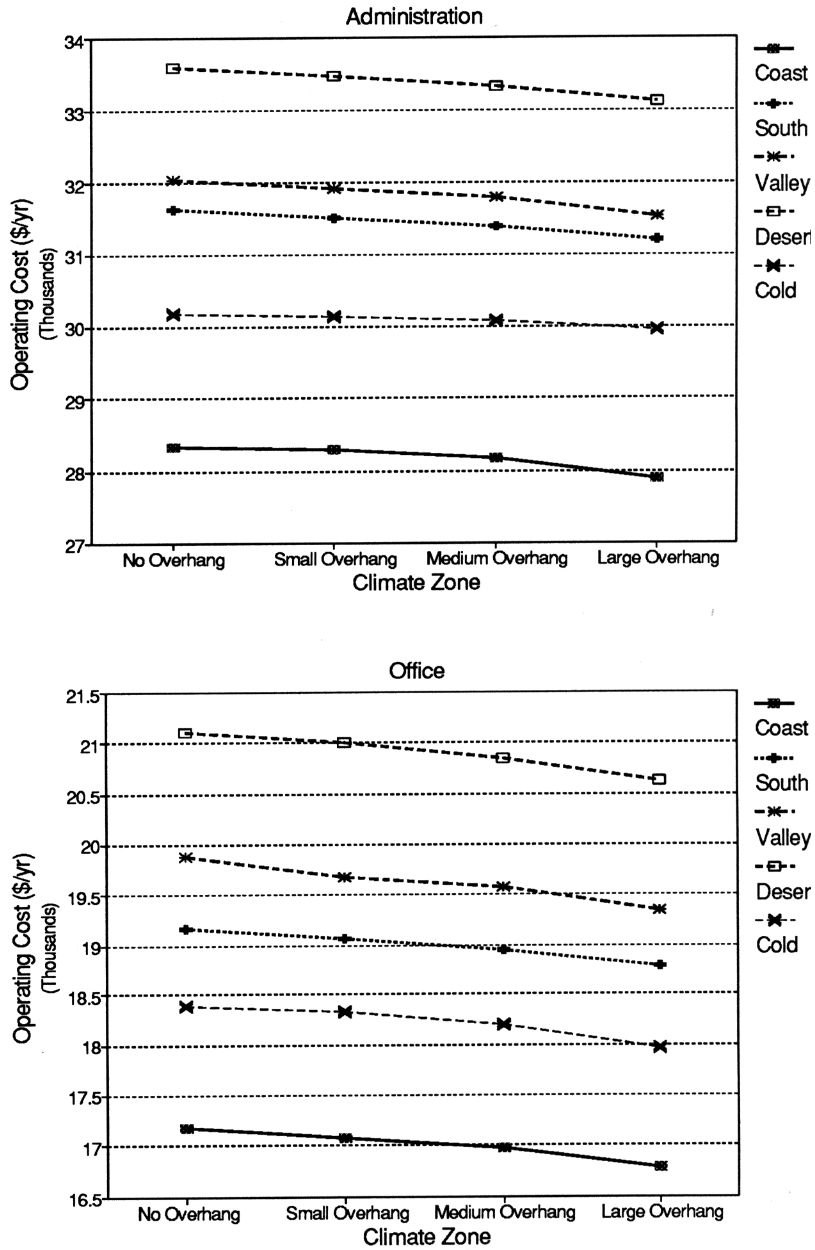


Figure 14 Energy Cost Impact of Overhangs

Skylights

Recommendation:
Use skylights and automatic lighting controls in the dayrooms of living areas, classrooms, and kitchens. Give consideration to security when selecting and locating skylights.

Skylights provide daylighting, satisfy needs for natural light, and can significantly reduce electric lighting requirements. Skylights can also provide natural light to the individual sleeping rooms if there is glazing in the doors.

Skylights can fill dayrooms with natural light, providing an atrium-like effect (Figure 15).

Daylighting in classrooms has been shown to improve students' learning performance.

High white skylights (translucent) or clear prismatic skylights provide the most uniform daylighting illumination and help reduce glare and high contrast. However, if skylights are the occupants' only visual contact with the out-of-doors, it may be desirable to use clear materials.

Clear skylights allow beam sunlight to cascade into the space, enabling occupants to distinguish between cloudy and overcast days, giving them a stronger connection with the out-of-doors.

Cost Effectiveness

Annual energy cost savings range from $0.35 to $0.40 per square foot of dayroom area in living areas. Simple payback ranges from six to seven years.

These savings include the additional cooling load resulting from increased solar gains as well as the electricity saved from reduced lighting energy.

Life-cycle cost reductions depend on climate and the type of lighting control.

Each 4x4 foot skylight will add about $1000 to the construction cost. This amounts to $1.40 per square foot of dayroom area. In addition, roughly $1.00 per square foot is required for daylighting controls.

Skylights only save energy if electric lighting is turned off when daylighting is available. Automatic daylighting controls turn off electric lights when sufficient daylight is available. See the lighting EEO for more information on daylighting controls.

Table 7 summarizes the

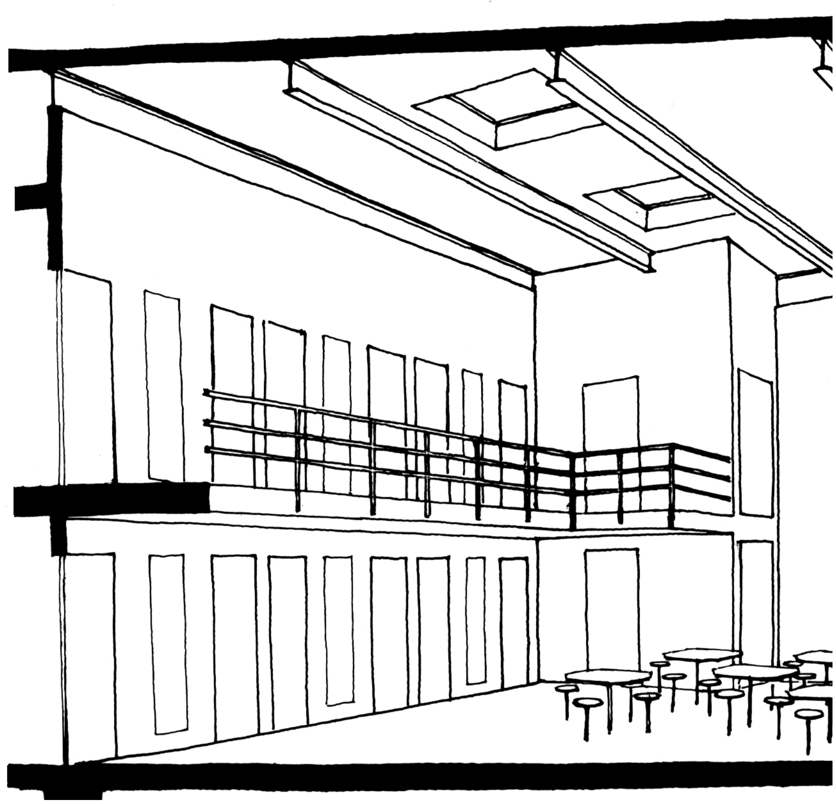


Figure 15 Skylights in Dayroom

Table 6 Optimum Skylight Area

			Optimum percent of Ceiling Area	
Glazing Type	**Solar Heat Gain Coefficient**	**Visible Light Transmission**	**Desert South**	**Valley Coast Mountains**
Clear	0.78	0.90	1.8	2.3
White	0.44	0.76	2.1	2.7

1) Skylight wells are assumed to be 4'x4' and 3' deep with a reflectance of 0.90 (well factor (WF) = 0.73).

2) Optimum effective aperture (EA) is 0.010 in Fresno and 0.015 in Los Angeles. EA = SRR × VLT × WF, where SRR is skylight-to-roof –ratio (skylight area/gross roof area) and WF is the "well factor" that represents the fraction of light absorbed by the skylight well.

cost-effectiveness of skylights.

Design Guidelines

Daylighting illumination is highly variable throughout the day and the year, and therefore careful design is required to provide adequate illumination while contributing the least possible amount to the cooling load.

Daylighting is about three times more thermally efficient than electric lighting. This means that the cooling load created by daylighting will be only one-third the cooling load created by electric lighting providing the same illumination.

The following general guidelines are offered to help properly design daylighting systems with skylights:

Select the right glazing material. Glazing materials have three principal performance characteristics:

- U-factor that determines conductive heat losses and gains.
- Visible light transmission (VLT) that determines the relative amount of daylighting that will enter the space.
- Solar heat gain coefficient (SHGC) that describes the fraction of solar heat gain that is transmitted. Clear glass has an SHGC close to 0.86, while reflective glass has an SHGC generally less than 0.35.

Glazing with a low U-factor should always be used. Plastic skylights should be either double or triple domed. Glass or polycarbonate skylights should be double paned and a low-emissivity coating should be considered to further reduce the U-factor.

Glazing for daylighting should have the highest possible VLT with the lowest possible SHGC. Clear or white plastic glazing reasonably satisfies this criterion. However, even better performance is available from spectrally selective glass products such as green or blue tints, certain low-e coatings, and special laminated glass inner layers.

Light transmission of plastic skylights can decrease as they age, although modern materials are less susceptible to change.

Provide the right skylight area. The optimum skylight area depends on the type of glazing that is used and the physical characteristics of the skylight well. Table 6 lists the optimum area for typical glazing materials and skylight well conditions.

The surfaces of the skylight well should be finished with a

> Skylights are used in the Rio Cosumnes Detention Facility in Sacramento County to bring natural light into the dayrooms. In this facility the deputies control the lights manually.
>
> San Bernardino County's West Valley Detention Center uses skylights in the day rooms. Electric lighting includes both HID and fluorescent systems, with the HID on programmable time controls and the fluorescent lights have dimmers with photocell control.
>
> The West Valley Juvenile Hall and the Placer County Juvenile Hall both have a number of skylights in the day rooms although the lights are manually, rather than automatically, controlled.

Table 7 Cost Effectiveness of Skylights

Climate	First Cost Premium ($/ft²)	Annual Energy Savings ($/ft²)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)
Living				
Coast	2.40	0.383	6.3	1.43
South	2.40	0.376	6.4	1.36
Valley	2.40	0.379	6.3	1.38
Desert	2.40	0.370	6.5	1.30
Cold	2.40	0.355	6.8	1.15

Assumptions

1) Results listed per square foot of dayroom area (2142 ft2 each).
2) Three 4x4 foot skylights in each dayroom.
3) Double white skylights (U-factor 0.7, SHGC 0.65, VLT 0.78).
4) 30 footcandles illumination setpoint.
5) 1.1 W/ft2 lighting power.
6) Costs include $1000 per skylight and $1/ft2 for dimming controls.

light color. Reflective materials may also be considered for deep skylight wells. The skylight well should be splayed, when possible, so that the skylight well is wider at the bottom than at the top where the skylight is located.

Skylight Distribution. Skylights should be spaced a distance about equal to the floor-to-ceiling height. This will provide good distribution throughout the dayroom. Avoid using a small number of very large skylights. More even light distribution is provided by a greater number of smaller skylights.

Lighting Illumination Controls. Very good skylight systems employ automatic controls to regulate the amount of electric lighting. These systems prevent over-lighting and reduce cooling loads.

Other Considerations. Skylights are available in a number of configurations including some with an integral curb. Skylight selection will depend on the design circumstances of each building.

Security bars are required under the skylights primarily to prevent entry rather than escape. The bars can be simply constructed of ½ inch steel welded on an 8x8 inch grid.

Operation and Maintenance

Although skylights are relatively maintenance free, they should be cleaned periodically to maintain light transmission. Use soap and water or follow manufacturers' recommendations.

Glazing

Recommendation:
Use double glazing with a low solar heat gain coefficient for administration and office areas in all climates.

Glazing selection is significant to the energy performance of buildings. The three glazing properties that designers should consider when choosing a glazing are solar heat gain coefficient (SHGC), visible light transmission, and U-factor (Figure 16). These items were previously defined in the Skylight Section.

The U-factor is affected by the number of panes of glazing, the type of frame, the window size, and for advanced glazing systems, the emissivity of special coatings applied to one or more of the glazing surfaces. The U-factor of windows in detention facilities should be less than about 0.64, the value for double glazing in a metal frame.

The SHGC should be as low as possible while maintaining adequate daylighting illumination. The SHGC is affected by the thickness of the glazing, the color of the tint (if any) and any special coatings that are applied to the glazing.

The visible light transmission (VLT) should be high enough to provide adequate daylight illumination. The window wall ratio (WWR) is defined as the total area of all window openings divided by the gross wall area. For areas where daylighting is desired, the WWR multiplied by the VLT should be about 0.18. This product is known as the effective aperture (EA). When the EA is 0.18 or greater, daylighting saturation will be achieved. Additional glazing area or light will be counter-productive, increasing cooling loads more than reducing lighting loads.

In general, the lower the SHGC, the lower the VLT. Some materials, however, have a high VLT relative to SHGC and should be considered for daylighting. These are generally known as spectrally selective glazings because they reflect or absorb solar infrared radiation while transmitting visible light. These products take the form of special blue or green tints or low-emmissivity (low-e) coatings. Most commercially available low-e coatings are only available for double glazed units. Table 8 compares the glazing properties of various types of glass

Cost Effectiveness

For an administrative building with a 30 percent WWR, changing from single pane tinted glass to double pane tinted units costs about $0.69

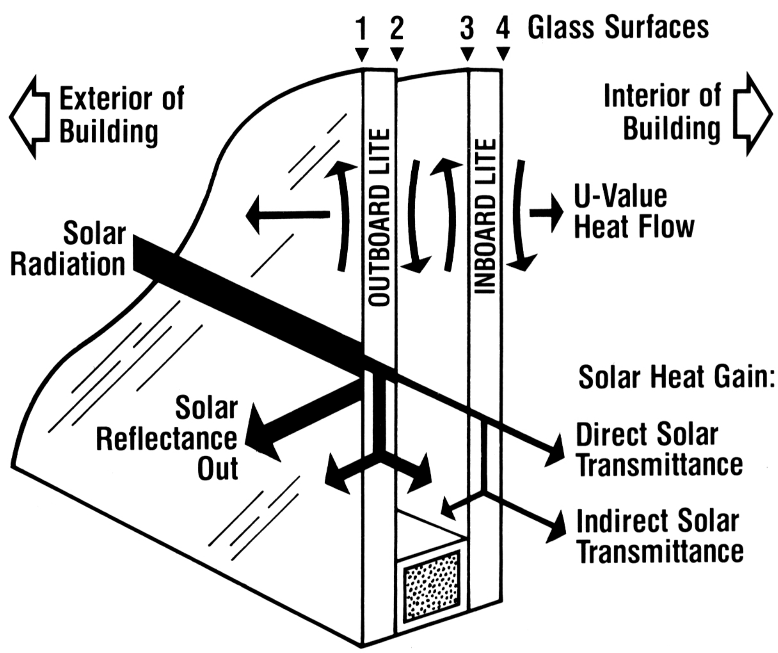


Figure 16 Dual Pane Glazing

per square foot of floor area and saves between $0.10 and $0.17 per square foot each year. This is a cost-effective investment since the simple payback is four to seven years.

The additional improvement from double pane tinted glass to double pane low-e glazing is also cost effective, especially in warm climates. The incremental payback is about seven years.

An additional economic benefit to choosing a low-SHGC glass is the reduction in cooling equipment capacity. Money saved on HVAC systems will help offset the extra glazing cost. Table 9 shows the cost-effectiveness of various glazing systems.

Design Guidelines

For energy efficiency the designer should specify the thickness, number of panes, tinting (if any) in the glass, the coating(s) to be applied and the surfaces to which the coatings are applied. For high performance glazings, it may also be necessary to specify a special gas (generally argon) that should be in the gap between the panes. These properties will determine the SHGC, VLT and U-factor.

Glass thickness is generally determined for structural reasons, but it affects the glazing properties significant to energy efficiency.

Although not an issue for energy efficiency, the glazing specification should indicate if the glass is to be heat strengthened or tempered.

Both reflective and low-e glass have a coating applied to one of the surfaces of the glass. This coating can be applied while the glass is in a molten state (pyrolytic

Table 8 Typical Glazing Properties

			U-factor	
	Solar heat gain coefficient	**Visible Light Transmittance**	**Metal Frame**	**Metal Frame with Thermal Break**
Single Glass				
Clear	0.81	0.89	1.13	n.a.
Green	0.58	0.74	1.13	n.a.
Grey	0.56	0.43	1.13	n.a.
High Performance Tint	0.50	0.67	1.13	n.a.
Medium Reflective	0.39	0.30	1.13	n.a.
High Reflective	0.19	0.08	1.13	n.a.
Double Glass				
Clear	0.70	0.78	0.64	0.57
Green	0.47	0.66	0.64	0.57
Grey	0.44	0.40	0.64	0.57
High Performance Tint	0.39	0.59		
Medium Reflective	0.29	0.27	0.64	0.57
High Reflective	0.13	0.07	0.64	0.57
Double Glass with Low-e Coating				
Clear	0.37 – 0.65	0.70 – 0.73	0.48 – 0.53	0.41 – 0.46
Green	0.30 – 0.42	0.60 – 0.61	0.48 – 0.53	0.41 – 0.46
Grey	0.24 – 0.39	0.35 – 0.37	0.48 – 0.53	0.41 – 0.46
High Performance Tint	0.27 – 0.34	0.53 – 0.55	0.48 – 0.53	0.41 – 0.46

1) SHGC and VLT for ¼ inch glass and do not include frame. Source: 1997 ASHRAE Handbook of Fundamentals, Chapter 29, Table 11.

2) U-factors take account of frame and edge effects and are for a fixed, 4'x4' window. Source: 1997 ASHRAE Handbook of Fundamentals, Chapter 29, Table 5

3) SHGC, VLT and U-factors for low-e coatings correspond to emmissivity range of 0.05 (better) to 0.20.

Table 9 Cost-Effectiveness of Various Glazing Types

	First Cost Premium ($/ft²)	Annual Energy Savings ($/ft²)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)
Admin Area - Single-pane tint to double-pane tint				
Coast	0.69	0.104	6.7	0.35
South	0.69	0.136	5.1	0.67
Valley	0.69	0.165	4.2	0.96
Desert	0.69	0.155	4.5	0.85
Cold	0.69	0.140	4.9	0.71
Admin Area - Double-pane tint to double-pane low-e (with low SHGC)				
Coast	0.92	0.099	9.3	0.07
South	0.92	0.133	6.9	0.41
Valley	0.92	0.138	6.7	0.46
Desert	0.92	0.123	7.5	0.31
Cold	0.92	0.099	9.3	0.07

Assumptions

1) Costs and savings listed per ft2 of floor area.
2) Single pane tint has SHGC of 0.61, center of glass U-factor of 1.09.
3) Double pane tint has SHGC of 0.49, center of glass U-factor of 0.48.
4) Double pane low-e has SHGC of 0.29, center of glass U-factor of 0.29.
5) Cost premium per ft2 glass area is $3 for double tint and $7 for double low-e.

coating) or after the glass has been manufactured (generally a vacuum sputter coating). The latter method provides better performance and is more expensive.

Glazing surfaces are numbered from the outside of the assembly (Figure 16). A coating on the outside surface of the inside pane of double glass is on the number three surface.

Glazing manufacturers provide technical data on their products, including the SHGC, VLT and U-factor. Most manufacturers offer low-e coatings and other high performance products.

The orientation of reflective surfaces on large buildings must be carefully considered to avoid creating safety hazards near highways or airports. Reflective surfaces can also have an impact on the cooling load of adjacent buildings.

4. Lighting Systems

Lighting in detention facilities is an extremely important element of energy consumption. In the office and administration areas, lighting represents about 50 percent of the total energy use and annual energy costs. In the living areas, the percent accountable to lighting is less, but still quite significant.

Several general principles to follow in the design of a lighting system for detention facilities are:

- Provide adequate light; do not overlight indoor and outdoor areas.
- Use the most efficient light sources.
- Use lighting controls to turn off the lights when not needed.
- Institute a program of routine maintenance and calibration to ensure that the lighting system is operated as efficiently as possible.
- Use detention grade fixtures, where applicable, to deter tampering and reduce maintenance costs.

How Much Light

In many cases, sleeping rooms and dayrooms in detention facilities are over-lit. For example, a four-lamp full-size fluorescent fixture is often installed in sleeping rooms where a two-lamp fixture would be adequate.

For juvenile facilities, the Board of Corrections requires only 20 foot-candles (fc) in areas where occupants are expected to read. It is not necessary to maintain 20 fc in other parts of the living area, such as circulation and television areas. Classrooms and other spaces outside the living areas should meet Illuminating Engineering Society (IES) recommended illuminance levels.

The IES uses the concept of illuminance categories to describe lighting needs. Typical spaces in detention facilities fall into one of six categories. The assignment of detention facility spaces to each illuminance category is shown in Table 10. Note that illuminance is not the only important criterion in lighting design, and typically a range of values is acceptable depending on the environment and the tasks to be performed.

By providing light sources that supply the recommended footcandle level, a designer can be sure that there is enough illumination to perform the tasks. Exceeding the recommended levels will waste energy on excess lighting.

Efficient Sources

Designers should choose the most efficient source of illumination and the most efficient luminaires, consistent with other needs such as the control of glare and ceiling reflectance (reflected glare).

Efficacy is a term that explains lighting efficiency and is measured by lumens per watt. Figure 17 illustrates the relative efficiencies of various lighting sources.

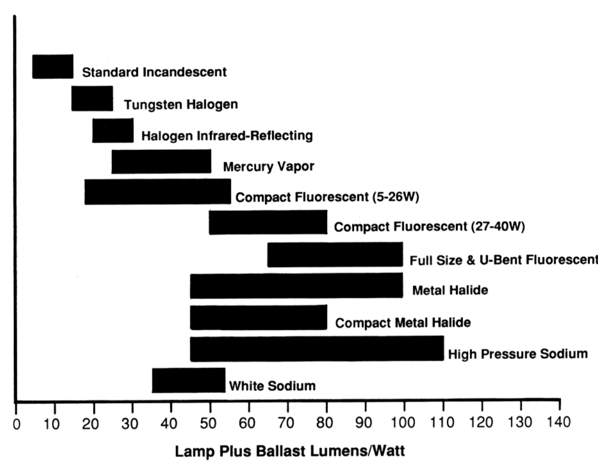


Figure 17 Lighting Source Efficacy

For some lamp types, note the wide range of efficacy. Fluorescent lamps range from about 60 to 100 lumens per watt. At the top end of the range are the newer, smaller diameter T-5 lamps with an efficient electronic ballast. At the lower end of the range are low-wattage compact fluorescents designed with high color rendering and intended as a substitute for incandescent lamps.

The least efficacious lamp is the incandescent lamp at less than 15 lumens per watt.

Lighting Power Density

The California Energy Commission recommends maximum lighting power densities (LPDs) for specific space types. The LPDs are measured in terms of watts per square feet (W/ft^2)These limits range from 0.6 W/ft^2 in corridors and restrooms to 2.0 W/ft^2 in auditoriums. Table 11 lists LPD limits for Title 24 space types

Table 10 Recommended Illuminance Levels

Illuminance Category	Recommended Illuminance (foot-candles)	Activity Description	Example Spaces
A	3	Public spaces with dark surroundings	Medical X-Ray
B	5	Simple orientation for short temporary visits	Data Processing Medical Ward Staff Dining Property Storage
C	10	Working spaces where visual tasks are only occasionally performed	Cell (general areas) Dayroom (general areas) Office Reception Corridors Locker Rooms Toilets Warehouse
D	30	Performance of visual tasks of high contrast or large size	Cell (reading area) Release Hold Room Holding Cell Visiting Booth Dayroom (reading areas) Offices Small Conference Room Commissary Linen Utility Laundry Program Classroom Gymnasium
E	50	Performance of visual tasks of medium contrast or small size	Central Control Workroom Nurse Station Nurse Records Medical Exam General Medical Laboratory Medical Supply Pharmacy Library Mail Room Kitchen General Maintenance Housing Control

Source: Illuminating Engineering Society Lighting Handbook, Ninth Edition, 2000.

commonly part of detention facilities.

To set a maximum lighting power target for the facility, first determine the floor area of each space type. Next, calculate the maximum lighting power for each of those space types using Table 11. Last, sum the total watts for an overall limit.

The power limits listed in Table 11 are high enough to provide recommended illumination levels as long as efficient lighting sources are used.

Lighting Controls

Install lighting controls that will enable building occupants to turn off lights when they are not needed, and reduce lighting to the necessary level.

Some lighting control strategies are further presented in this chapter as energy efficiency opportunities (EEOs). These include occupancy sensors and daylighting controls.

Others to be considered include:

- Separate manual switching in every enclosed room.
- Bi-level illumination of all rooms larger than 100 ft^2, so that lighting can be reduced when maintenance crews are on duty and during other periods.
- Automatic time clocks for lighting circuits used on predictable schedules.

Lighting Quality

The design of a lighting system should address more than just the general considerations of quantity of illumination. In all areas of a detention facility, energy efficient luminaires will save energy, and reduce the operating and maintenance costs of the facility. The following recommendations will improve the quality and performance of lighting systems:

- In office areas, specify luminaires that do not reflect onto computer screens.
- Areas with inmate access must have luminaires that cannot be damaged.
- Lightening the interior surfaces of rooms by painting the walls white or light colors. This can reduce lighting energy by reducing the number of luminaires required. This is especially appropriate in cells and dayrooms.
- Shield light sources from central control rooms to prevent glare from interfering with correctional officers' line of vision.
- Use high intensity discharge (HID) or fluorescent lights instead of incandescent lamps wherever possible.
- Do not overlight. Use Table 10 to determine the proper amount of

Table 11 Maximum Lighting Power Densities

Area Categories (from Title 24 Energy Standards)	**Maximum Lighting Power Density (W/ft^2)**
Auditorium	2.0
Classrooms, lecture, training, vocational room	1.6
Commercial and industrial storage	0.6
Corridors, restrooms, stairs and support areas	0.6
Dayrooms	1.1*
Dining	1.1
Electrical, mechanical rooms	0.7
Exercise center, gymnasium	1.0
Kitchen, food preparation	1.7
Laundry	0.9
Library	
Reading areas	1.2
Stacks	1.5
Lobbies:	
Main entry lobby	1.5
Reception/waiting	1.1
Locker/dressing room	0.9
Lounge/recreation	1.1
Medical and clinical care	1.4
Office	1.3
Precision commercial or industrial work	1.5
Sleeping rooms	1.2*

Note: Partial list from Title 24, 1999 area category limits. * Limits for dayrooms and sleeping rooms are not in Title 24 but are listed here as equal to limits for lounge/recreation area and library reading area, respectively.

illumination.

Maintenance and Calibration

After a lighting system is installed, it is important to institute a program of routine maintenance and calibration of controls.

Compact fluorescent lamps have a life of about 10,000 hours and full-size fluorescents last about 20,000 hours. It is best to periodically replace them in groups. When the lamps are replaced, the luminaires should be cleaned.

Time clock settings need to be checked and calibrated from time to time because patterns of use change.

Photocells connected to automatic dimming controls need to be adjusted so that only the proper amount of illumination is provided.

Exterior Lighting

Exterior lighting systems should provide between two and six foot-candles. Base illumination of less than two foot-candles can be sufficient for perimeter areas when “impact” alarm lighting is provided. That is, full lighting is instantly triggered if the perimeter zone is penetrated.

For outdoor parking lots and walkways outside the secure area, IES recommends 0.2 to 0.5 foot-candles minimum illumination, with the higher value for enhanced security.

Lighting System Availability

Table 12 identifies the recommended lighting systems for various spaces and their cost-effectiveness. These lighting systems are discussed in the next sections.

Table 12 Lighting Systems Applicability Matrix

EEO	Page #	Recommendation	Living Areas	Admini-stration	Kitchen
Daylight Activated Controls	36	Use daylight activated lighting controls at perimeter office spaces, in the dayrooms of living areas and in other areas where daylight is available.	$$$	$$$	N.A.
High Intensity Discharge Lighting	39	Specify high intensity discharge (HID) lighting in place of fluorescent lighting where dimming or frequent switching is not required.	$$$	$$$	$$$
Cell Lighting	42	Use a single two lamp fluorescent fixture in sleeping rooms to meet minimum illuminance requirements.	$$$	N.A.	N.A.
Occupant Sensors	46	Install occupant sensors in individual offices, conference rooms and other intermittently used areas of a detention facility.	N.A.	$$$	$$$
Compact Fluorescent Lamps	48	Specify compact fluorescent lamps for all locations that typically use incandescent lamps.	$$$	$$$	N.A.
Electronic Ballasts	50	Specify solid state electronic ballasts for all full length fluorescent lamps.	$$$	$$$	$$$

Key:
$$$ Cost Effective
N.A. Not applicable

Daylight Activated Controls

Recommendation:
Use daylight activated lighting controls at perimeter office spaces, in the dayrooms of living areas and in other areas where daylight is available.

Daylight activated controls turn lights off or dim lights when daylight is adequate to meet lighting needs. A photocell measures illumination and sends signals to a controller that reduces the lighting power when levels exceed the design illumination level (Figures 18 and 19)

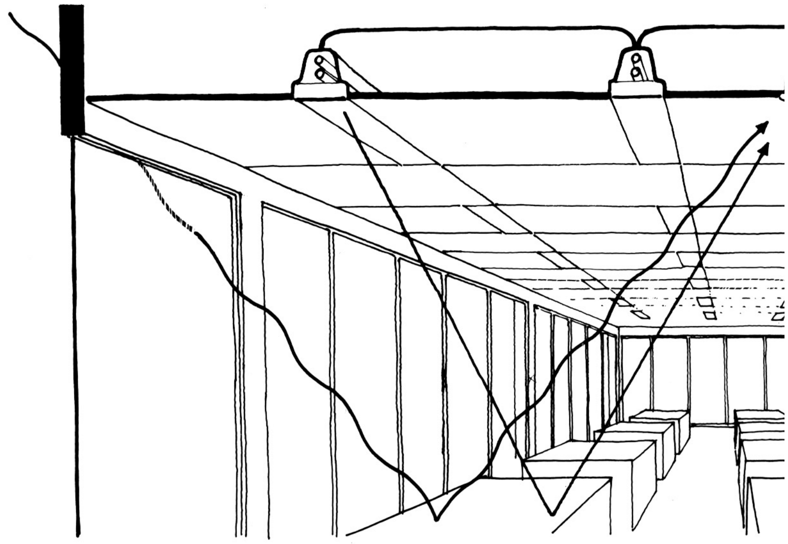


Figure 18 Large Zone Daylighting Control System

Cost Effectiveness

Automatic daylighting controls cost about $0.50 to $1.00 per square feet depending on whether they are on/off or dimming type controls. On/off controls require a photocell and controller, and dimming systems usually require a special ballast. The savings range from $0.15 to $0.27 per square foot of daylighted area, providing a payback of four to seven years depending on the window area. Table 14 summarizes the cost-effectiveness of daylight activated controls.

Daylighting effectiveness depends on several factors. The visible light transmission (VLT) of the glass, the window-wall ratio (WWR), and the design illuminance level. These terms were discussed in the sections on Skylights and Glazing.

The availability of natural light in perimeter spaces is related to the effective aperture (EA) of the glazing.

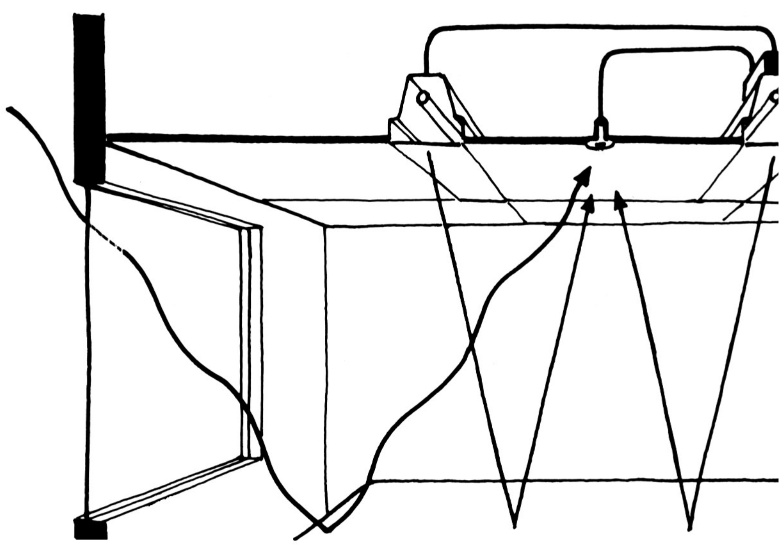


Figure 19 Small Zone Daylighting Control System

Table 13 Effective Aperture (EA)

	VLT	WWR=.15	WWR=.30	WWR=.45
Single glass				
Clear	.88	.13	.26	.40
Green	.75	.11	.22	.34
Bronze/Gray	.52	.08	.16	.23
Reflective	.30	.04	.09	.13
Double				
Clear	.78	.12	.23	.35
Green	.66	.10	.20	.30
Bronze/Gray	.46	.07	.14	.21
Reflective	.26	.04	.08	.12

1) VLT; Visible light transmittance
2) WWR; Window wall ratio (total area of window openings divided by gross wall area)
3) Optimum EA is generally about 0.18. EA = WWR x VLT

The EA is defined as the WWR multiplied by the VLT of the glazing. As the EA increases, lighting energy is reduced, but cooling energy increases. An optimum EA results when the sum of the lighting energy and the cooling energy is minimized. The optimum EA is generally about 0.18.

Even if the glazing design is not optimal, savings will usually occur, and daylighting controls should still be considered. Table 13 shows the EA for different glazing designs.

Design Guidelines

Lighting controllers can be either a dimming or stepped type.

Dimming controls provide a smooth balancing of electric light and daylight. The imperceptible change in electric lighting makes dimming desirable in office areas where stepped controls can be disruptive. With electronic ballasts, dimming controls can reduce lighting levels gradually from 100 percent down to five or ten percent.

Stepped controls shut off circuits of lamps or luminaires in increments to maintain a specified light level. A lighting system with two lamps per luminaire could be operated by a two-step controller. The first step turns off one lamp of each luminaire. As daylight levels increase, the second step turns off the remaining lamps. Stepped controls are less expensive than dimming controls. The noticeable reduction in light levels with stepped controls, however, can be disturbing to the occupants of the space.

Stepped controls should be used in areas where precise lighting levels are less critical, and abrupt changes in electric light output are acceptable. Stepped daylighting controls are appropriate and cost-effective in the sky lit dayrooms of living areas. Refer to the section on Skylights for more information.

For daylighting controls to be most effective in office areas, the luminaires should be arranged in rows parallel to the windows. This arrangement permits a successive reduction of electric lighting for luminaires near the windows.

For single offices, a single room daylighting controller integrated with an occupancy sensor is recommended. Refer to the later discussion on occupant sensors for more information.

Table 14 Cost Effectiveness of Daylight Activated Controls

	First Cost Premium ($/ft²)	Annual Energy Savings ($/ft²)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)
Administration				
Small Aperture (EA=.06)	1.00	0.15	6.6	0.52
Med. Aperture (EA=.18)	1.00	0.25	4.1	1.47
Large Aperture (EA=.30)	1.00	0.27	3.8	1.66

Assumptions

1) Lighting power density 1.3 W/ft2.
2) Costs and savings listed per square foot of daylighted area.
3) Design illuminance is 50 footcandles.
4) Hours per day savings:
    EA=0.06: 4 hours;
    EA=0.18: 6.5 hours;
    EA=0.30: 7 hours.

High Intensity Discharge Lighting

> Recommendation:
> Specify high intensity discharge (HID) lighting in place of fluorescent lighting in the dayrooms and in other high bay areas where dimming or frequent switching is not required.

Appropriate HID sources include metal halide and color improved high pressure sodium lamps. The efficacy (lumens/watt) is somewhat higher for HIDs than fluorescent lighting systems. For instance, it is 95 lumens per watt for HIDs versus about 85 lumens per watt for T-8 fluorescent lamps with electronic ballasts. Table 15 compares the efficacy of different types of lamps. This allows HIDs to operate with fewer watts to obtain the same illumination.

Lower wattage compact HID lamps are also available which can be substituted for high wattage incandescent or compact fluorescent luminaires in administration and office lobbies. While not as efficient as the higher wattage HID lamps, the compact lamps have better color rendition and are more appropriate for office and administration areas.

When using HIDs with daylighting controls, such as in sky lit areas, the controls should be the stepped type rather than the dimming type. Dimming controls are available for HID lamps but the lamp efficacy and color rendition are reduced.

Cost Effectiveness

HID luminaires may be cost effective in applications with high ceilings and where restrike constraints are not a concern. Fewer fixtures are required for an HID system when compared to fluorescent alternatives.

Design Guidelines

HIDs have a warm-up time of two to four minutes and a restrike time of 10 to 15 minutes. Even the shortest power delay necessitates a cooling off period in order for the lamp to be restarted. In this regard, HIDs are not recommended as the only light source in high security areas.

All HID lamps require ballasts to operate. In addition, some of these lamps require an external starting aide. Starting aides generate high-voltage pulses needed to begin the lamp arc. Ballasts maintain a stable current to keep the lamp operating at its optimum level. Electronic ballasts are typically more efficient due to lower losses than standard electro-magnetic ballasts.

Pulse-starting lamps and ballasts are about 20 percent more efficient than standard HID lamps and ballasts. Other advantages include less lumen degradation, color shifting and reduced re-strike time (four to five minutes) compared to standard lamps. Pulse starting lamps and ballasts cost about 15 percent more than standard HIDs.

Generally, HIDs are not recommended where the ceiling height is less than ten feet due to uneven light distribution. HIDs should be placed in high ceiling locations to avoid occupant contact with them. Closed luminaires should be specified for safety reasons because HID lamps sometimes rupture when they burn out.

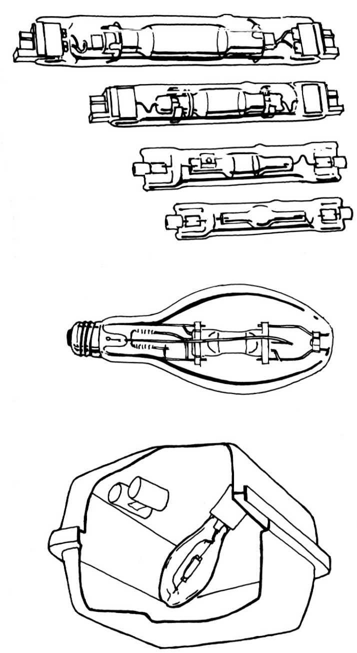


Figure 20 HID Lamps

Table 15 Comparison of Lumens per Watt for Different Lamps

Lamp	Watts	Lumens/Watt	Lamp Life (hours)
HID, Metal Halide	250 (294 W input) 400 (460 W input) 1000 (1080 W input)	70 80 100	7,500 – 10,000 15,000 – 20,000 9,000 – 12,000
HID, High Pressure Sodium	250 (300 W input) 400 (465 W input) 1000 (1100 W input)	75 105 125	24,000 – 40,000 24,000 – 40,000 24,000 – 40,000
Fluorescent, T-8, electronic ballast	32	85	20,000
Fluorescent, T-5, electronic ballast	32	95	20,000
Compact Fluorescent	40	60	10,000
Incandescent	All	15	1,000 – 6,000

Lumens per watt for lamps vary due to different manufacturers and different lamp ballast combinations. Numbers shown include ballast losses.

For administration and office lobbies, compact HID fixtures are available as a direct replacement for incandescent fixtures. The compact HIDs have the same screw-type bases as incandescents.

HID exterior fixtures are excellent for lighting buildings, yards, parking lots, and other perimeter areas due to their high power, efficiency, and point-source capability.

For either exterior or interior applications, HID fixtures should be used where lights are left on for long periods or switched on a time clock.

When quick restrike time is required, alternatives for providing high-bay illumination include: a) compact fluorescent luminaires with several lamps, b) T-8 fluorescent fixtures and c) high output T-5 fluorescent fixtures. A comparison of the economics of the compact fluorescent fixtures with the T-8 fixtures and metal halide fixtures are described in the Case Study.

The high output T-5 fluorescent fixture system requires about half the number of lamps and ballasts

Case Study: The following table summarizes the cost-effectiveness of various options for illuminating the dayrooms in the planned Ventura County Juvenile Justice Center. Assumptions: 1) baseline lighting power density (LPD) of 1.1 watt/square feet, 2) annual operating hours 4,380, 3) average of 20 fc, 4) weighted average electricity rate of $0.0547/kWh and $7.70/kW, 5) discount rate 6 percent, 6) labor rates corrected to Southern California. The analysis shows that the T8 fluorescent with electronic ballast option was more cost-effective compared to other alternatives primarily due to lower initial cost and lower recurring annual cost.

Option	Estimated Annual kWh/year	Estimated Annual Energy Cost	Estimated Installed Cost	Project Net Present Value Compared to T8/EB Option
Pulse starting metal halide	104,000	$8,000	$40,000	($16,600)
T8 fluorescent lamps with electronic ballasts (EB) in three and four lamp fixtures	103,000	$8,000	$30,000	NA
Compact fluorescent fixture with four to six 42 watt CFL	80,000	$7,000	$50,000	($40,600)

as a T-8 system while providing the same level of illumination. This results in fewer lamps and ballasts to maintain. Both the compact fluoresent, the T-8 and T-5 system work well in conjunction with skylights and daylighting controls. Fluorescent fixtures can be separately controlled and do not have the long restrike times associated with HID fixtures. In addition, compact fluoresent luminaires can also have multiple levels of illumination and can be controlled separately.

Cell Lighting

Recommendation:
Use a single two-lamp fluorescent fixture in sleeping rooms to meet minimum illuminance requirements.

The current state standards for cell lighting in detention facilities require that a minimum lighting level of 20 fc be provided at the personal grooming area and at areas where occupants are likely to read. Typically, this requirement is met by providing one surface mounted, two-lamp luminaire in the center of the ceiling (Figure 21).

From an energy efficiency perspective, cells should be designed so that the lavatory is adjacent to the writing table. In this type of cell layout, one ceiling or wall mounted light fixture with two F32 lamps can meet the illumination requirements for both task areas (Figure 21). In fact, the single two-lamp fixture may provide 20 fc throughout the space if room surfaces are a light color.

When the lavatory is not located adjacent to the writing desk, two separate fixtures can be specified. These fixtures can be two task lights equipped with compact fluorescent lamps, or one task light plus one ceiling-mounted (straight tube) fluorescent fixture (Figure 22 and Figure 23)

Cost Effectiveness

Cost effectiveness for the three options is shown in Table 16.

Option I (Figure 21) is the most cost effective, saving about 60 watts per room and $0.11 per square foot each year (for sleeping room area). This option uses half the energy of a four-lamp fixture design. However, this option depends on relative locations of the grooming and writing areas, and may not provide sufficient illumination for reading at the head of the bed against the end wall.

Option II (Figure 22) reduces power by about 68 watts per cell saving $0.12 per square foot annually whereas Option III (Figure 23) reduces power by about 34 watts per cell, saving $0.06 per square foot per year.

Option III provides adequate light for reading both at the writing surface and over the head of the bed, as well as higher general illumination of the cell, which may be a significant advantage over the other options.

An added advantage of using task lighting is that the number of hours of lamp operation may be reduced if occupants have control, since only one luminaire need be used for a single task.

Design Guidelines

Placement of fixtures. When using Option I the fixture should be ceiling

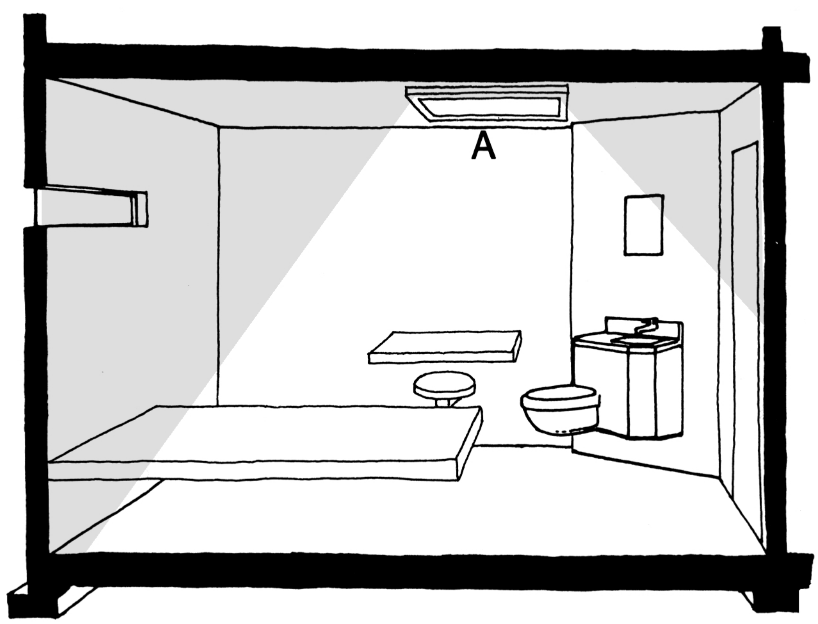


Figure 21 Cell Lighting Option I

mounted or mounted on the corner between the ceiling and the wall. It should be centered between the desk and the lavatory mirror for optimum lighting. Angled fixtures are available that are installed in the corner where the wall meets the ceiling.

For Option II or III, the task light at the lavatory (Type B- see Figure 25) should be placed directly above the mirror and equipped with two 13-watt compact fluorescent lamps with separate ballasts. The second task light should be centered between the writing surface and adjacent bunk. Depending on the type of lamp enclosure selected, the luminaire may be ceiling mounted, wall mounted, or mounted on the corner between the ceiling and the wall. Wall or corner luminaires should be selected with a tilted surface to direct the light towards the task surface.

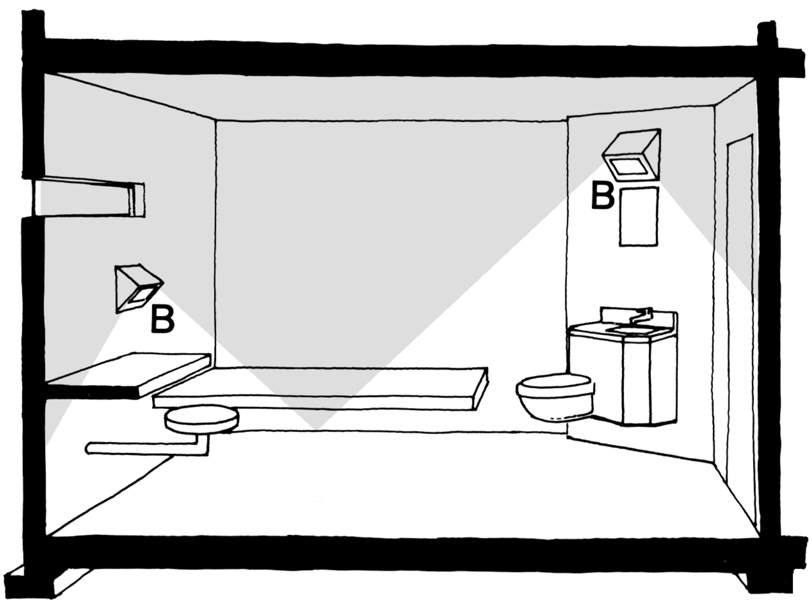


Figure 22 Cell Lighting Option II

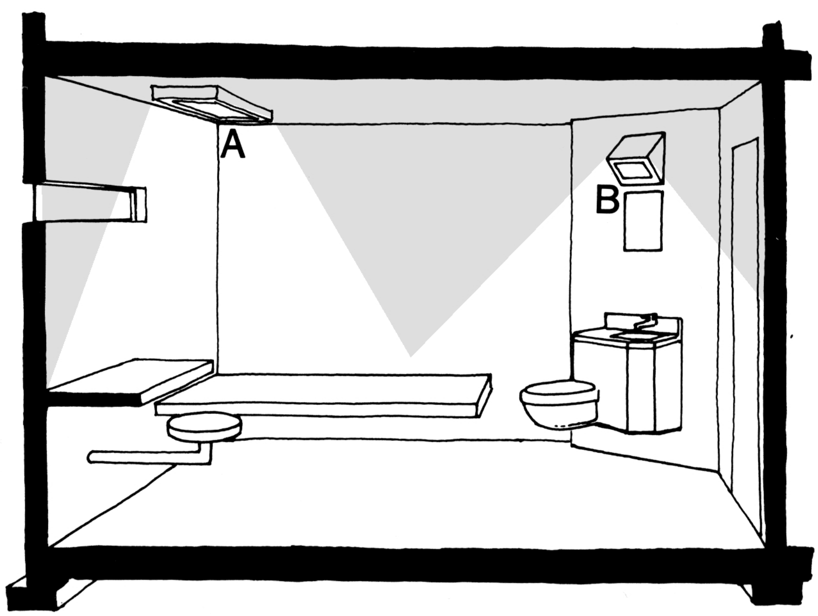


Figure 23 Cell Lighting Option III

Lamps and Ballasts. Two 4-foot F32 (T-8) lamps should be used in fixture Type A (Figure 24), ceiling mounted luminaire with a two-lamp ballast.

Fixture Type B (Figure 25) should generally have two 7 to 13-watt, twin tube compact fluorescent lamps (CFLs).

Maximum security luminaire manufacturers can fit various kinds of lamp sockets to their products. The compact fluorescent lamp and ballast should be selected at the same time as the luminaire to ensure compatibility.

Specify electronic ballasts for both full-size and compact fluorescent lamps. Electronic ballasts are quieter, flicker-free and more energy efficient than magnetic ballasts.

Low-mercury fluorescent lamps are available that offer environmental and maintenance benefits. Standard fluorescent lamps must usually be treated as hazardous waste when disposed while low-mercury lamps may be exempt from these requirements.

Luminaires. Standard features of maximum security

Figure 24 Fixture Type A

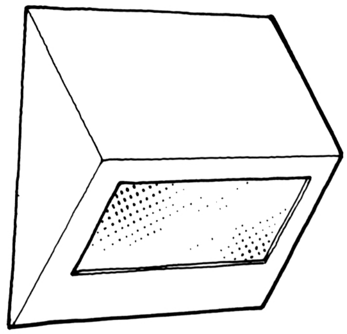
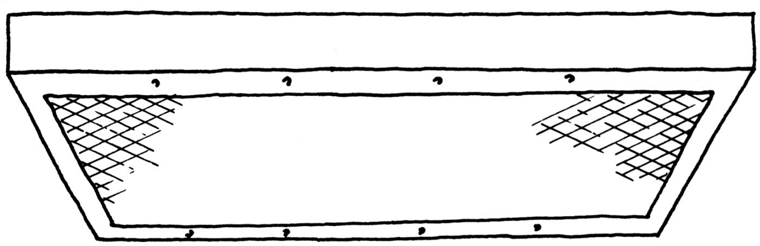


Figure 25 Fixture Type B



luminaires include heavy gauge steel enclosures, tamper resistant screws and concealed hinges with welded end pins that prevent removal.

Task light luminaires are available in under cabinet, wall mounted, or ceiling mounted styles. The lens surface of wall and corner mounted luminaires is often tilted at a slight angle to direct the light towards the task.

Since operation of cell lights are typically controlled from a central location, overriding switches should be provided to turn the lamps off early from within the cells. When the cell lamps are turned off, either from a central location or by the occupant, at least one of the fixtures should include low-wattage (4 watt) night lights to provide night observation.

Room Color. Ideally, the walls and ceilings of cells should be painted a light color to increase surface reflection. Painting will increase maintenance costs.

Table 16 Cost-Effectiveness of Cell Lighting Options

	First Cost Premium ($/ft²)	Annual Energy Savings ($/ft²)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)
Cell Lighting				
Option I	0.00	0.11	0.0	1.05
Option II	0.50	0.12	4.2	0.69
Option III	0.50	0.06	8.4	0.10

Assumptions

1) Baseline is one four-lamp, T-8 fixture per cell.

2) Option I consists of two F32 (T8) lamps.

OptionII uses four 13-watt cfls.

Option III uses two F32s (T8) and two 13-watt cfls.

3) Assumes six operating hours per day.

Occupant Sensors

> Recommendation:
> Install occupant sensors in individual offices, conference rooms and intermittently used areas.

Occupant sensors turn lights off when rooms are unoccupied. They sense the presence of humans by either sound (ultra-sonic), heat (passive infrared radiation) or a combination of both technologies (Figure 26).

When a room is unoccupied for a set period of time, occupant sensors turn lights off. The shut-off delay can be set from 1 to 20 minutes, depending on the manufacturer's or facility's programmed settings. Typically, the delays are set at 12 minutes. This keeps the lights on when people stop moving or leave the room for a short period of time. The delay also prevents premature lamp failure related to frequent on-off operation. The lights can also be manually controlled with these systems. Figure 27 shows typical types of occupancy sensors.

Many occupancy sensor designs have automatic "off" with manual "on." This has the advantage of ensuring that lights will be on only when required.

Small zone applications include offices, conference rooms, locker rooms, and other rooms used intermittently. Large zone applications include open offices, large conference rooms and workshops.

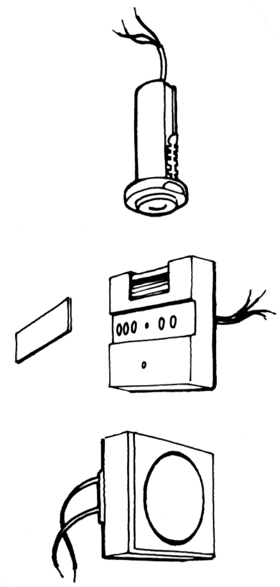


Figure 27 Typical Occupancy Sensors

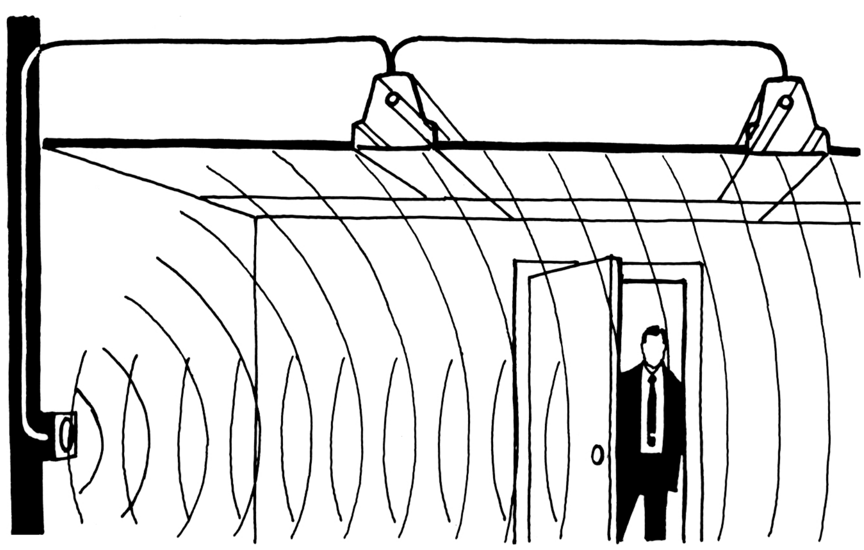


Figure 26 Wall-Mounted Ultrasonic Occupancy Sensor

Cost Effectiveness

Occupant sensors typically reduce lighting hours by 20 to 30 percent. A 30 percent reduction in lighting hours would save about $0.13 per square foot of controlled area in administration areas. The estimated cost is $0.38 per square foot for small zone occupancy sensors and $0.25 per square foot for large zone occupancy sensors. The payback period for this investment ranges from 2.4 to 3.1 years. See Table 17 for a summary of occupancy sensor economics.

Table 17 Cost Effectiveness of Occupancy Sensors (Single Technology)

	First Cost Premium ($/ft^2)	Annual Energy Savings ($/ft^2)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft^2)
Occupancy Sensors				
Administration	0.32	0.13	2.4	0.99
Kitchen	0.25	0.08	3.1	0.57

Assumptions

1) Cost listed per square foot of area controlled by occupancy sensors.
2) Installed costs are:
   $0.38/ft2 for small zone sensors.
   $0.25/ft2 for large zone occupancy sensors.
3) Small area sensors save 30 percent, large area sensors save 20 percent.
4) In administration areas, 50 percent of sensors are small area and 50 percent large area.
5) Kitchen controlled by large area sensors.

Where dual technology sensors are required, the cost is roughly 50 percent higher, resulting in 3.6 to 4.7 year paybacks.

Design Guidelines

Occupancy sensors have a maximum range and angle of operation. Placement should be determined based on the type of area the sensor is to control. A good location is in the middle of the ceiling or on a wall that does not face the door. This prevents movement in a hall or corridor from interfering with operation. Ceiling location also helps prevent vandalism.

Ultrasonic sensors are typically specified in open office plans and in other spaces where there may not be a direct line-of-sight between the sensor and occupants. Locate ultrasonic sensors an adequate distance from supply air diffusers or false triggering may occur.

Infrared sensors are often specified in conference rooms and individual offices. They need a direct line-of-sight to detect occupants. Additionally, some occupancy sensors have integrated daylighting controls to provide additional savings. See the previous EEO for more information on daylighting controls.

Dual-technology units are available that combine both ultrasonic and passive infrared sensors. These are useful in areas where false triggering may occur (e.g. lights turn on when someone passes outside a door of an unoccupied room) or when lights fail to stay on in an occupied space.

Using these technologies, there are many design variations including the following:

- Wall switch replacements with integral infrared or ultrasonic sensors (suitable for retrofit);
- Manual-on, automatic-off controls (recommended for greater savings);
- Ceiling mounted sensors wired to remote controls and/or wall switches.

In order to work properly, occupancy sensors must be commissioned in the field. Specify that each sensor be tested after installation for full coverage, proper sensitivity, and correct time delay.

Compact Fluorescent Lamps

Recommendation:
Specify compact fluorescent lamps with separate electronic ballasts for all locations that typically use incandescent lamps.

The energy efficiency, good color rendering, and small size of compact fluorescent lamps make them an ideal substitute for incandescent lamps (Figure 28). The rare earth phosphors used in these lamps produce a very high color rendering light that is similar to incandescent light. Compact fluorescent lamps are good choices for task lights, wall sconces, and down lights. However, they are less efficient than full size fluorescent lamps and are not appropriate for general office lighting.

Cost Effectiveness

In most cases, the return on investment for compact fluorescent lamps is less than two years when compared to incandescent lamps. In the administration area compact fluorescents pay for themselves in only one year.

Compact fluorescent lamps operate at approximately one-third the wattage of incandescent lamps for the same level of illumination. Compact fluorescent lighting with a lighting power density (LPD) of 1.0 watt per square foot offers the same illuminance as a system with an LPD of 3.0 watts per square foot using incandescent lighting.

Compact fluorescents typically cost $40 more per fixture than incandescent fixtures. This increased cost is largely offset by their longer life rated at 10,000 hours, which is ten times that of incandescent lamps.

Design Guidelines

Compact fluorescent luminaires can be used for illumination in corridors, and in offices for task lights and under-counter lights.

Like all fluorescent lamps, compact fluorescents require a ballast. The ballast can be integral or separate from the lamp. Lamps with a medium Edison base have an integral ballast in the base. All other compact fluorescent lamps

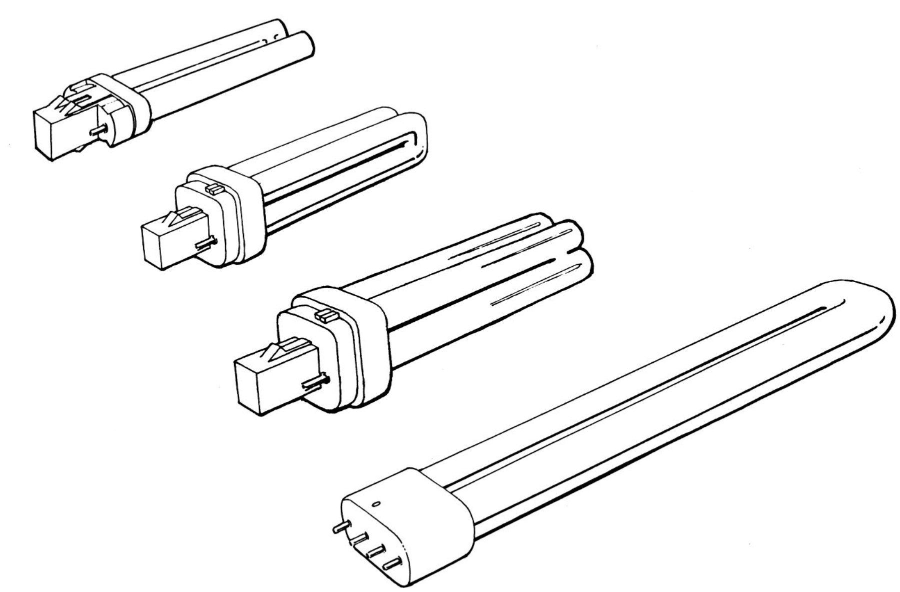


Figure 28 Compact Fluorescent Lamps

have a separate ballast. For new construction the separately ballasted lamp is the preferred choice (Figure 29). It performs more efficiently than a lamp with an integral ballast and the energy savings potential cannot be circumvented by relamping with an incandescent lamp. In addition, the ballast can outlive the lamp, reducing the cost of replacement.

In existing buildings, the integrally ballasted lamp can be retrofitted into existing incandescent lamp fixtures.

Specify electronic ballasts for all compact fluorescent lamps.

Refer to the Cell Lighting Section for a description of a compact fluorescent lamp application in sleeping rooms.

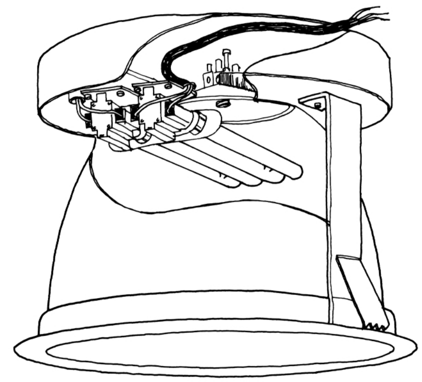


Figure 29 Compact Fluorescent Luminaire

Electronic Ballasts

Recommendation:
Specify solid state electronic ballasts for all full length fluorescent lamps.

Electronic ballasts are more efficient than magnetic ballasts. The solid state circuitry has fewer losses and they drive the lamps at a higher frequency. The 120 or 277 volt, 60 hertz power supplied to the ballast is rectified and converted to high frequency power, usually from 20 to 40 kilohertz (Figure 30). Fluorescent lamps operate more efficiently at a higher frequency and the size, weight, lamp flicker and ballast noise are reduced.

Cost Effectiveness

Electronic ballasts are the standard for new construction. The slight cost premium over magnetic ballasts results in a payback of less than one year.

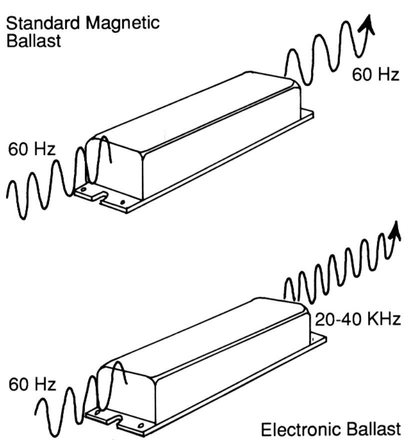


Figure 30 Ballast Comparison

Design Guidelines

Electronic ballasts can be specified for all full-size fluorescent lamp luminaires throughout a detention facility. They are available in both instant start and rapid start models. Instant start electronic ballasts can reduce lamp life, but this is compensated for by extremely high energy efficiency.

Substituting electronic ballasts for magnetic ballasts is easy because they have the same size and shape and use the same wire color coding. Each ballast is designed to operate a particular set of fluorescent lamps. Matching the ballast and lamp is essential to achieving the lumen output and rated lamp life.

Electronic ballasts are applicable where dimming is desired. However, special dimming (adjustable output) ballasts are required. With photo sensor control, dimming ballasts can provide daylighting savings. The extra cost for dimming ballasts range from $30 to $40 per ballast. Additional cost for controls is also required for dimming systems. See the previous sections on daylighting controls.

Electronic ballast specifications should include the manufacturer, the product number and the

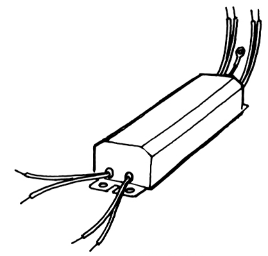


Figure 31 Fluorescent Lamp Ballast

output characteristics. In addition, ballasts should be selected for high power factor (greater than 0.85) and low total harmonic distortion (less than 10 percent). Specify a ballast factor appropriate for the application. Typical ballast factors are about 0.9. This means that the lamps will provide 90 percent of their rated light output. In some cases a ballast with a higher ballast factor provides enough light to avoid the use of a fixture with more lamps.

Magnetic and electronic fluorescent ballasts, like computers and motor speed controls, generate line current harmonics. These harmonics can produce power quality problems, which could adversely affect the operation of electrically sensitive equipment. In wiring designs where the lighting circuits are isolated by floor from other circuits, these harmonic currents can be controlled. Problems with early electronic ballast designs are largely solved. In fact, most generate less harmonic current than magnetic ballasts.

5. Mechanical Systems

Introduction

The architect and mechanical designer have significant latitude when conceptualizing and designing the heating, ventilating and air conditioning (HVAC) systems. There are many opportunities to incorporate energy efficient systems that are more cost effective to operate than standard systems. This chapter provides both design guidelines and specific project suggestions to reduce operating cost.

Summary of Design Guidelines

For all mechanical systems:

- Follow the minimum outside air guidelines.
- Select the most cost effective energy source.
- Use variable speed fan drives to meet varying airflow requirements for space conditioning and smoke management.
- Minimize pressure drop in constant volume air handling systems.
- Specify premium efficiency motors.
- Use economizers to modulate outside airflows.
- Include variable air volume temperature control in office areas.
- Use separate units to supply areas not occupied continuously, allowing them to be turned off when the areas are unoccupied.
- Select high efficiency packaged equipment.
- Mechanically fasten all duct connections and seal joints with mastic.

For central plant HVAC systems:

- Use high efficiency chillers and consider variable speed chillers.
- Specify cooling towers with 4°F approach.
- Install variable speed drives and building controls to optimize the use of circulating pumps.
- Use pump staging and controls for chilled water and hot water systems.
- Insulate all hot and chilled water pipes and fittings.
- Use a storage tank and/or controls to reduce the cycling of the boiler.
- Design boiler systems to allow turning off the circulation loop pumps when heating is not needed.

For domestic hot water systems:

- Optimize hot water use in showers by using low flow shower heads.
- Insulate all hot water pipes, tanks, and fittings.
- Install time clocks to minimize the use of circulating pumps.
- Install controls and stage pumps to optimize energy consumption for variable load.
- Minimize standby losses and auxiliary equipment energy consumption by sizing heating equipment to operate at 80 to 90 percent capacity.

HVAC System Selection

Two major types of HVAC systems are installed in detention facilities: package units and central plant systems.

Package units use individual furnaces and compressors located at each air handler. Within the package unit, the condenser may be air-cooled (typical), evaporatively precooled, or evaporatively cooled. A package unit may also include a direct/indirect evaporative cooler for the supply air.

Central plant systems generate hot water and chilled water centrally and distribute them to the air handlers. Chillers can be air-cooled or water-cooled. Package units are used in many detention facilities because of their low installation cost. However, some detention facilities are large enough to justify a central plant, which has a higher capital cost but provide a good return on investment. The better efficiency of the central plant will be especially cost effective in hot areas of the

Table 18 HVAC System Comparison

	Package Units				Central Plant	
	Air Cooled Condenser	**Evap Pre-Cooled Condenser**	**Evap-Cooled Condenser**	**Direct/ Indirect Evap**	**Air Cooled Chiller**	**Water Cooled Chiller**
Installation cost per ton	Low	Medium	High	High	Medium	High
Energy cost per ton	High	Medium	Low	Low	Medium	Low
Maintenance cost per ton	Medium	Medium	High	High	Medium	Medium
Type of facility	Any	Medium or Large	Medium or Large	Medium or Large	Medium or Large	Medium or Large
Zone scheduling flexibility	High	High	High	High	Low	Low

Note: Costs will vary significantly depending on layout of the facility, but as a rough guide the cost ranges are equivalent to Low ($1,500 to $1,750 per ton), Medium ($1,750 to $2,000 per ton) and High ($2,000 to $2,250 per ton).

state. In addition, a central plant is a good choice for facilities with large, multi-story buildings.

Table 18 compares the cost of various HVAC systems.

Ventilation and Airflow Requirements

The amount of outside air ventilation has a large impact on heating and cooling energy costs, especially in the living areas. A minimum amount of ventilation air is necessary to dilute contaminants and odors. However, using more outside air than necessary increases energy consumption. System design should balance these two factors by using enough, but not too much, outside air ventilation. In addition to outside airflow rates, total supply flow rates are an issue in system design. Airflow must be high enough to provide adequate heating and cooling and to deliver ventilation air to occupants. However, energy consumption increases with higher airflow. System airflow should be chosen carefully to provide adequate ventilation performance without wasting energy.

A third consideration is exhaust requirements. Toilets, showers, living areas and kitchens all face exhaust requirements to control odors, reduce moisture or remove other contaminants. This exhaust air is typically sent outside, though this is not required in every case. In addition, smoke exhaust systems may be required.

The appropriate choices for outside air flow, supply air flow and exhaust air flow can be confusing because the requirements and recommendations are covered by several sources.

Outside air. Minimum outside airflow rates are based on the number of occupants. Recommendations range from 5 to 20 cubic feet per minute (cfm) per person. Title 24 energy standards set a minimum of 15 cfm per person, which is a reasonable choice for detention facility design. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 62 also includes ventilation guidelines equal to 20 cfm per person.

Exhaust air. The exhaust airflow rate recommended by the California Department of Corrections is 55 cfm per cell. The Title 24 requirement for rooms with a sink or toilet is 5 air changes per hour, which equals about 45 cfm for a 70 square feet cell. This air does not need to be exhausted directly to the outdoors unless the room contains a shower or bathtub. If the room does not contain a shower or bathtub, the exhaust air may be recirculated and diluted with ventilation air. Therefore, around 50 cfm per wet cell is a reasonable design target for exhaust. Designers must also check smoke exhaust requirements.

System Design

Most jails are designed with single zone systems serving large living areas. This is an efficient system provided that outside air economizers are used in sequence with the heating and cooling, that two-speed or variable speed fans are used, and that efficient heating and cooling sources are used. In areas where additional temperature control may be desired, such as office areas, variable air volume systems are an efficient choice. Systems to be avoided include multi-zone, constant volume dual duct, and constant volume reheat.

Most air handlers operate continuously in a detention facility because the building is always occupied. Exceptions include: kitchens, laundries, multi-purpose rooms, visiting rooms, classrooms, attorney rooms, and some office spaces. The mechanical system operating cost would be reduced if these areas were designed to have separate air handlers, controls, or package units. These units should be controlled by electronic time clocks to reliably shut them off when not needed while also maintaining override capability at central control.

Load Calculations and System Sizing

System capacity over sizing is a common source of inefficiency. Airflow may be greater than necessary leading to wasted fan energy. Excess cooling capacity causes equipment cycling and more operation at partial load, which is typically less efficient. Oversized equipment is usually more expensive and causes higher project costs.

There are two elements to proper system sizing: accurate heating and cooling load calculations and appropriate equipment selection. Energy savings and initial cost savings can often be achieved merely through more careful calculations and equipment sizing.

Load calculations are based on many assumptions, and one of the most important assumptions is the interior design conditions: maximum allowed indoor temperature for cooling and minimum temperature for heating. While administrative areas should follow standard design practices such as those in ASHRAE Standard 55, living areas for detainees might face less stringent standards. In some cases, the relaxed cooling design temperature may allow the use of an evaporative system as the only source of cooling. At the very least, it allows selection of smaller and often less expensive equipment.

The indoor design temperature used for load calculations must be chosen during the early planning phase of a project. The appropriate choice depends on regulations and the type of environment desired. The following regulations and guidelines may apply.

- California Board of Corrections, Minimum Standards for Local Detention Facilities (Adult) Title 24, Part 1: “comfortable living environment”.
- California Board of Corrections, Adult Guidelines, Title 24, Part 1: 66°F to 78°F in summer, 63°F to 73°F in winter.
- California Department of Corrections, Design Criteria Guidelines: Cooling to 78°F for administrative areas and 92°F for inmate spaces (to allow evaporative cooling). Heating for a minimum of 68°F.
- American Correctional Association, Standards for Adult Local Detention Facilities: Summer 66°F to 86°F and winter 61°F to 73°F.
- ASHRAE Standard 55-1992: About 68°F for heating and 78°F for cooling, depending on humidity and the surface temperature of walls, windows, ceiling and floor.

In reality, comfort depends not only on temperature, but also humidity and air movement. People are comfortable at higher temperatures with some air movement such as that provided by ceiling fans. Therefore, designers may stretch the temperature limits for comfort if they provide air movement.

In detention facilities, ventilation load is also significant. For living spaces, outside air can account for one-third to two-thirds of the peak cooling load. Therefore, minimizing outside air, while meeting ventilation requirements, is important in allowing smaller equipment selection. Note that systems with an economizer will often operate with higher than minimum outside air, and minimum ventilation occurs only during warm and cold periods.

California's Title 24 energy standards and ASHRAE's Standard 90.1 set guidelines for equipment selection. In brief, they state that cooling equipment shall be no larger than the calculated cooling load plus 10 percent for a safety factor and an allowance of 10 percent for cool-down loads. However, in areas occupied 24 hours per day, such as the living areas, there will be no cool-down loads, and the extra allowance may be unnecessary.

Heating System Fuel Comparison

There are typically four types of heating fuels: natural gas, propane, fuel oil, and electricity. Packaged units can operate on natural gas or propane; boilers can operate on natural gas, propane, or fuel oil. Electricity is used for resistance (strip) heat, boilers, and heat pumps.

There are many considerations when selecting the most appropriate energy source. One of the most important is operating cost. Since these different energy sources have different heating values, this must be considered in choosing the least expensive alternative.

Electricity prices have traditionally been regulated. Deregulation has resulted in future price uncertainties. Selecting energy efficient equipment will help minimize energy price shocks.

Natural gas may be purchased from the local utility at regulated rates or directly from energy service providers or from aggregation pools. See Appendix B for more information on purchasing electricity and gas in California's competitive markets.

Liquid fuels are available from local dealers at prices depending on supply and demand. Rather than purchasing propane at a fluctuating price each month, one can negotiate lower prices for an entire year when the year's supply is guaranteed to one supplier. In addition, installing larger storage tanks, to reduce the frequency of refilling and to shift purchases to the summer, can reduce the unit price. Many municipalities have reduced energy costs through this process.

Table 19 compares the energy sources on a cost per million Btu basis of typical heating fuels. Check the

Table 19 Heating System Fuel Comparison for Medium-Sized Customers

Heating Source	Typical Fuel Cost	Cost ($ per million Btu)
Electric Resistance Heat (3,414 Btu/kWh)	$0.08/kWh	$23.44
Electric Heat Pump (6.6 Btu/Wh heating)	$0.08/kWh	$12.12
Propane * (95,475 Btu/gallon)	$0.80/gallon	$10.47
No. 2 Fuel Oil * (138,960 Btu/gallon)	$0.80/gallon	$7.20
Natural Gas * (100,000 Btu/therm)	$0.65/therm	$8.13

* $/million Btu includes 80 percent combustion efficiency

relative fuel prices and air pollution equipment requirements for specific fuels to evaluate the best choice for a project.

In most California locations, natural gas is the least expensive heat source. Heat pumps are typically more expensive, although the impact is less in warm climates than in cold. Electric resistance is the most expensive heat source and should only be used as backup for heat pumps.

If propane is used, there may be special precautions necessary for security and safety purposes. Depending on facility needs, particular attention may be needed for siting the storage tank.

Central Plant Design Considerations

Central plants are appropriate for larger detention facilities that can justify the higher equipment costs with the reduced operating costs. These plants typically include boilers and chillers.

Systems should be designed to operate efficiently at partial load conditions as well as at full load.

For chilled water plants, consider a variable speed chiller or multiple staged chillers. Oversize the cooling tower to provide lower condenser water temperature to improve chiller efficiency. Use two-way valves on cooling coils to create a variable flow system. Consider a primary-only variable flow system in which the flow varies in the chiller evaporator coil (check manufacturer minimum flow). Use variable speed pumps.

Boiler systems can also be designed to facilitate turning off the distribution system when conditions allow. To minimize potential thermal shock maintenance problems, it may be desirable to keep boilers hot during times when their load does not last all day. This is typically done by maintaining flow through the boiler. The most appropriate design strategy is a small pony pump and a three-way valve to circulate water through the boiler when the main loop is turned off. Secondary loops should use variable speed pumps and two-way valves.

Boiler thermal shock problems are minimized by using boilers having a bent tube design. These absorb the thermal expansion and contraction within the flexed tube design and are designed to be turned off when there is no load.

Controls

Although a variety of control systems are available, the type of mechanical system typically dictate the controls. These can be classified as electric, electronic, pneumatic, or direct digital controls (DDC).

A simple single-zone package air handling system will typically come with electric controls consisting of a thermostat placed in the conditioned space. The thermostat may offer time of day control in addition to temperature control.

A more elaborate package system such as a multi-zone or variable air volume (VAV) unit will typically come with electronic controls. These are usually dedicated controls, designed to match the specific requirements of the system.

Modern built-up air handling systems should have field installed DDC controls. These are microprocessor-based controls that can perform any of the functions of the other types of control systems. In addition, DDC controls can be programmed to provide functions like supply air temperature reset, optimal fan start, and supply air pressure reset. DDC controls can also be applied to packaged systems. The advantages of DDC controls include improved accuracy of control, easy remote monitoring and control of operations, and flexibility in control strategies. On the other hand, DDC systems require trained staff for programming and system maintenance.

Pneumatic controls consist of a network of tubing connected to sensors and actuators that communicate via air pressure. These controls are uncommon in new facilities and should only be considered for extensions of existing HVAC systems.

Motor Selection

Premium efficiency motors are available for almost every application. These motors reduce energy use by minimizing losses inherent to all motors. The most cost effective applications have high operating hours, typically HVAC fans and pumps.

Tables 20 and 21 show the recommended efficiencies for electric motors. Table 22 is a matrix comparing the cost-effectiveness of various energy efficiency measures for mechanical systems.

Table 20 Recommended Electric Motor Efficiencies – Totally Enclosed Fan-Cooled Motors (Percent)

hp	3600 RPM Premium Efficiency	Best Available	1800 RPM Premium Efficiency	Best Available	1200 RPM Premium Efficiency	Best Available
1	78.5%	80.4%	85.5%	86.5%	82.5%	85.5%
1.5	85.5%	87.5%	86.5%	87.5%	87.5%	87.5%
2	86.5%	87.5%	86.5%	86.5%	88.5%	88.5%
3	88.5%	89.5%	89.5%	89.5%	89.5%	90.2%
5	89.5%	89.5%	89.5%	90.2%	89.5%	90.2%
7.5	91.0%	91.7%	91.7%	91.7%	91.7%	91.7%
10	91.7%	91.7%	91.7%	91.7%	91.7%	92.4%
15	91.7%	91.7%	92.4%	93.0%	92.4%	92.4%
20	92.4%	92.4%	93.0%	93.6%	92.4%	93.0%
25	93.0%	93.6%	93.6%	94.1%	93.0%	93.0%
30	93.0%	93.6%	93.6%	94.5%	93.6%	93.6%
40	93.6%	94.1%	94.1%	94.5%	94.1%	94.5%
50	94.1%	94.1%	94.5%	95.0%	94.1%	94.5%
60	94.1%	94.5%	95.0%	95.4%	94.5%	95.0%
75	94.5%	95.0%	95.4%	95.4%	95.0%	95.0%
100	95.0%	95.8%	95.4%	95.4%	95.4%	95.4%
125	95.4%	95.8%	95.4%	96.2%	95.4%	95.8%
150	95.4%	96.2%	95.8%	96.2%	95.8%	96.2%
200	95.8%	96.2%	96.2%	96.5%	95.8%	95.8%

Table 21 Recommended Electric Motor Efficiencies – Open Drip-Proof Motors (Percent)

hp	3600 RPM Premium Efficiency	Best Available	1800 RPM Premium Efficiency	Best Available	1200 RPM Premium Efficiency	Best Available
1	80.0%	84.0%	85.5%	86.5%	82.5%	82.5%
1.5	85.5%	86.5%	86.5%	86.5%	86.5%	87.5%
2	86.5%	86.5%	86.5%	88.5%	87.5%	88.5%
3	86.5%	87.5%	89.5%	90.2%	89.5%	90.2%
5	89.5%	91.0%	89.5%	90.2%	89.5%	90.2%
7.5	89.5%	90.2%	91.0%	91.7%	91.7%	91.7%
10	90.2%	91.7%	91.7%	91.7%	91.7%	92.4%
15	91.0%	91.7%	93.0%	93.0%	92.4%	92.4%
20	92.4%	93.0%	93.0%	93.6%	92.4%	93.0%
25	93.0%	93.0%	93.6%	94.1%	93.0%	93.6%
30	93.0%	94.0%	94.1%	94.1%	93.6%	93.6%
40	93.6%	94.5%	94.1%	94.1%	94.1%	94.5%
50	93.6%	94.1%	94.5%	95.0%	94.1%	94.5%
60	94.1%	94.5%	95.0%	95.4%	95.0%	95.4%
75	94.5%	95.4%	95.0%	95.4%	95.0%	95.8%
100	94.5%	95.8%	95.4%	95.8%	95.0%	95.4%
125	95.0%	95.4%	95.4%	95.8%	95.4%	95.8%
150	95.4%	96.2%	95.8%	96.2%	95.8%	95.8%
200	95.4%	96.2%	95.8%	96.2%	95.4%	96.2%

Table 22 Mechanical Systems Applicability Matrix

EEO	Page #	Recommendation	Living Areas	Adminis tration	Central Plant
Outside Air Ventilation	58	Reduce the amount of outside ventilation air to the minimum required.	$$$	$$$	N.A.
Evaporative Cooling	60	Consider direct/indirect evaporative cooling in living areas for all climate zones.	$$$	$$$	N.A.
Thermal Energy Storage Systems	62	Consider thermal energy storage systems for large detention facilities .	N.A.	N.A.	$$$
Cogeneration Systems	64	Consider cogeneration systems for large detention facility projects with central plants, particularly in areas where natural gas is available, electricity is expensive, and facilities have high thermal loads.	N.A.	N.A.	$$$
Variable Speed Pumping	66	Use primary/secondary or primary-only variable speed pumping on medium to large chilled water pumping systems.	N.A.	N.A.	$$$
High Efficiency Boilers	69	Consider high efficiency pulse boilers for space heating and domestic hot water.	N.A.	N.A.	$$$
Chilled Water Plant Design	71	Use high-efficiency, water-cooled, variable speed chillers. Use chiller heat recovery if there is a reliable hot water demand.	N.A.	N.A.	$$$
High Efficiency Cooling Tower	75	For systems with a cooling tower, select an induced draft unit with axial fan.	N.A.	N.A.	$$$
High Efficiency Packaged Equipment	78	If packaged equipment is chosen (versus no cooling, evaporative cooling, or central plant), then select models with high EER and IPLV ratings. Use evaporative precooling of outside air, and evaporative pre-cooling of condenser air or evaporatively cooled condensers, as appropriate.	$$$	$$$	N.A.
Duct Sealing and Insulation	80	Create strong and long-lasting connections by mechanically fastening all duct connections and using mastic to seal connections and transverse joints (those perpendicular to airflow).	$$$	$$$	N.A.

Key:
$$$ Cost Effective — EER = Energy Efficiency Ratio
N.A. Not applicable — IPLV = Integrated Part Load Value

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Outside Air Ventilation

Recommendation:
Reduce the amount of outside air ventilation to the minimum required.

Living areas typically have outside air ventilation rates that far exceed the minimum requirements. It is common practice for facility staff to provide the living areas with 100 percent fresh air.

High outside air ventilation rates have a significant effect on annual energy costs as well as air handling equipment costs. Larger coils and fans must be installed in the air handlers to satisfy the increased cooling and heating loads that occur with high ventilation rates.

For areas where 100 percent outside air is required, such as medical isolation rooms, use a heat recovery system. Heat recovery is especially cost-effective in hot and/or cold regions of the state.

In areas like classrooms that are intermittently occupied, carbon dioxide (CO_2) sensors can be used to reduce ventilation air when the space is unoccupied.

Minimizing outside air ventilation rates will yield significant energy cost savings. See the introduction to this Chapter for more information on airflow rates.

Cost Effectiveness

Significant energy cost savings result from reducing outside air ventilation in the living areas from 100 percent to the minimum required for cell exhaust. Savings are between $0.16 and $0.53 per square foot of living area when minimum outside air is reduced to between 40 percent and 70 percent depending on climate.

If ventilation is reduced to the minimum Title 24 energy standards, 15 cfm/person, then savings increase to $0.30 to $0.73 per square foot depending on climate. At this point, the minimum outside air fraction is about 20 to 30 percent. Table 23 shows the variation of outside air and its effect on energy savings. To achieve these savings, return air from the sleeping rooms must be recirculated and diluted.

Design Guidelines

Detention facility cells with a toilet and hand basin require outdoor air ventilation flow rates that are higher than for ordinary living areas. When stipulating outside air for cells, ensure that applicable standards or codes are met. In most cases, this means approximately four air changes per cell per hour (45 cfm/cell). See the introduction to this Chapter for information on outside air requirements.

While minimum outside air ventilation rates may reduce the size of air handling equipment, fire protection regulations require higher air flows for smoke management. In this case, either two-speed motors or variable speed drives should be installed with oversized air handler fans. The lower speed can be used for normal space conditioning and the high speed can be used for smoke management. Note that although steps must be taken to ensure that fire regulations are met, it is important that space conditioning air flow rates be calculated independently.

It is recommended that all air handlers have an economizer cycle to allow maximum use of outside air for space conditioning. The control system should ensure that the outside air ventilation rates be set to minimum levels when outdoor conditions are not favorable. Provisions should be made to allow the facility staff to increase the flow rate up to 100 percent if necessary.

Carbon dioxide (CO_2) sensors are an option for further energy savings. They control the amount of ventilation air based on CO_2 concentration in the space or in the return air. The amount of CO_2 is a good indicator of the occupancy level in the space.

Table 23 Variation of Outside Ventilation Air

Space Type/Climate	First Cost Premium ($/ft²)	Annual Energy Savings ($/ft²)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)
Decrease Outside Air from 100% to Min Necessary for Cell Exhaust (40% to 70% min)				
Coast	n.a.	0.16	0.0	1.65
South	n.a.	0.32	0.0	3.25
Valley	n.a.	0.45	0.0	4.53
Desert	n.a.	0.53	0.0	5.32
Cold	n.a.	0.45	0.0	4.48
Decrease from 100% to Min Necessary for Occupants (20% to 30% min)				
Coast	n.a.	0.30	0.0	3.05
South	n.a.	0.45	0.0	4.47
Valley	n.a.	0.63	0.0	6.32
Desert	n.a.	0.73	0.0	7.34
Cold	n.a.	0.72	0.0	7.22

Assumptions

1) Savings presented per square foot of living area.

Evaporative Cooling

Recommendation:
Consider direct/indirect evaporative cooling in living areas for all climate zones.

Evaporative cooling is an alternative way to provide air conditioning. Lower energy costs result because no compressor is needed, only a fan and pump. Combining indirect and direct evaporative cooling minimizes the moisture added to the air.

Evaporative cooling is most effective in hot, dry climates but it can also be used to completely replace compressor cooling in cold and coastal areas.

Packaged air handlers are available that incorporate both indirect and direct evaporative cooling. The evaporative cooling system has an economizer that uses 100 percent outside airflow during cooling mode and minimum outside airflow during the heating mode. This allows the use of return air during heating season to keep heating costs equivalent to a standard system.

Alternatively, a combination of cooling tower and heat exchanger could be used with cooling coils and standard air handlers.

Cost Effectiveness

Energy and demand charges are reduced when an evaporative cooling system is installed instead of a mechanical refrigeration system. If no supplemental refrigeration is installed, evaporative cooling is cost-effective in all cases. While evaporative systems may cost somewhat more to install than standard rooftop packaged air conditioners, the energy savings more than make up for the difference.

Evaporative cooling will be most cost effective in the coast and cold climate zones. However, for all hours in all climate zones, evaporative cooling will maintain space temperatures below 86°F in the living areas. Table 24 shows the effectiveness of evaporative coolers in various regions in California.

See the later section on High Efficiency Packaged Equipment for information on cost effectiveness of adding evaporative cooling to a standard rooftop unit.

Installation of evaporative cooling in kitchens can provide a cost-effective cooling source while eliminating the need and expense for conventional air conditioning.

Design Guidelines

Evaporative cooling can provide all cooling needs in dry mountain or desert areas such as Mt. Shasta City (89°F/61°F design dry bulb/wet bulb) or Bishop (100°F/60°F).

For areas with higher design wet bulb temperatures, such as Sacramento (100°F/70°F), evaporative cooling can produce most of the space

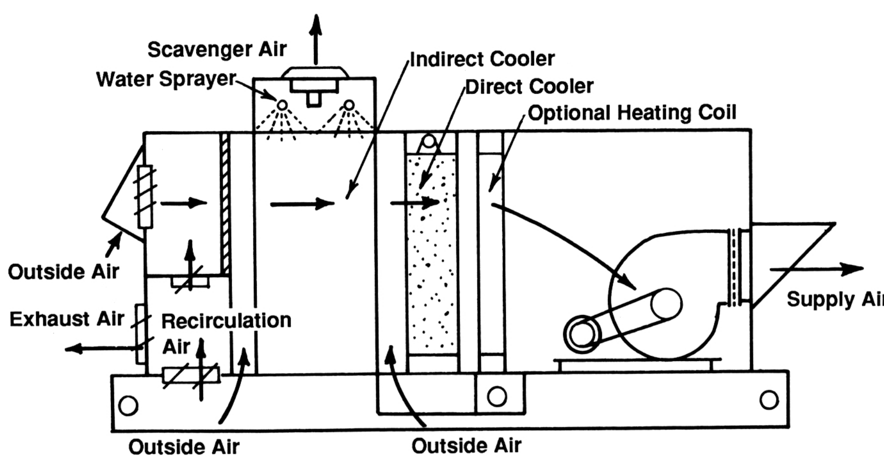

Figure 32 Indirect Evaporative Cooler

cooling needs. If evaporative cooling is used exclusively, space temperatures may rise above 80°F during design conditions. This may be acceptable in living areas, but is usually unacceptable in office and correctional officer areas where an independent air conditioning system can be used. During the few days near design conditions, supplemental air conditioning can be used as a second cooling stage in cells and dayrooms.

Table 24 Evaporative Cooler Effectiveness

		Hours per Year Inside Temperature is:		
		Above 75°F	**Above 80°F**	**Above 85°F**
Living	Coast	0	0	0
	South	460	17	0
	Valley	829	134	0
	Desert	1218	346	0
	Cold	253	0	0

Assumption: Hours shown are for a 20,000 cfm evaporative cooler.

Evaporative coolers demand more maintenance than a typical compressor-based system, so they should be specified only for facilities with qualified maintenance staff or with a qualified outside service company.

To minimize maintenance requirements, specify adequate bleed-off rates to prevent mineral buildup without causing excessive water consumption. Also specify controls that periodically flush the evaporative medium with water to remove dirt and scale. Finally, specify materials to minimize potential for corrosion.

Packaged evaporative coolers are available in a wide range of sizes, approximately 3,000 to 20,000 cfm. They are typically roof mounted to supply outside air for the indirect cooling stage. Without adding moisture, indirect cooling stage is approximately 60 percent effective in reducing the dry bulb temperature of the makeup air to its wet bulb temperature.

The California State Prison in Corcoran has both direct and indirect type evaporative coolers for the housing units. This facility houses 4,500 inmates. The facility reports some problems with their direct evaporative coolers but no major maintenance problems with the indirect units

Ventura County's Todd Road Jail uses evaporative cooling in the print shops and kitchen.

Thermal Energy Storage Systems

Recommendation: Consider thermal energy storage systems for large detention facility projects.

Thermal energy storage (TES) systems are used to store energy generated during electric utility off-peak hours for use during the on-peak (and possibly partial-peak) period. They are most appropriate for facilities with large cooling loads and a central chilled water plant and access to low cost off-peak electricity. TES equipment is typically installed in or near the central plant area where no additional security precautions would be required.

The most prevalent systems include chilled water storage systems, ice builders with outside-in melt, inside-out melt, ice harvesters and eutectic salt phase change systems.

TES systems are not appropriate for facilities having distributed direct expansion air conditioning units.

Cost Effectiveness

Although TES systems do not reduce energy use, they do lower energy costs by shifting energy use to off-peak hours when kWh energy charges and kW demand charges are typically lower.

The cost effectiveness of a TES system must be evaluated for each specific case because cooling load patterns, applicable utility rates, available space, and system incremental costs can vary from one project to the next. In the restructured electricity markets, TES may be useful as a load management strategy to help facilities reduce energy costs.

Construction costs for TES systems typically range from $100 to $125 per ton-hour of storage capacity. Other incremental costs to consider are operating staff training, additional maintenance, and extra controls.

TES will be most cost effective in hot parts of the state, where the energy costs for cooling are high enough to justify the extra construction cost. In the desert climate zone, one example analysis shows annual utility savings of $11,800 and an additional installed cost of $260,000.

Design Guidelines

The local utility may offer special rate structures and other incentives for TES systems. Before preparing a feasibility study, inquire on the extent of these programs. In addition, consider future electricity rates that might

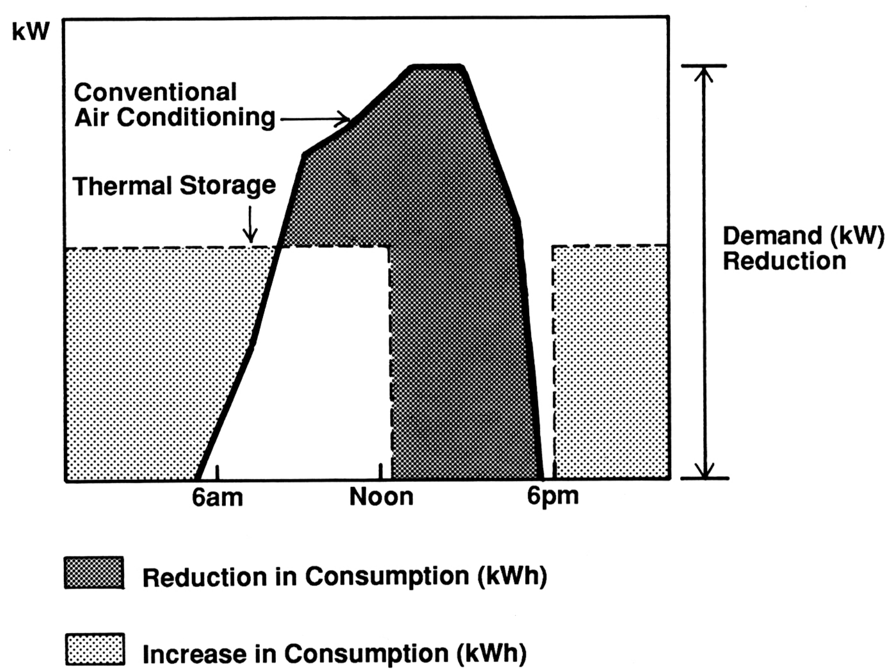

Figure 33 Thermal Energy Storage Systems

provide more incentive for load management strategies. The designer should discuss the various storage options with equipment suppliers and/or a consultant before committing to a particular system. The effect of downsizing equipment should be considered. Often one or more chillers can be eliminated. Chiller, pump, and piping sizes can be reduced when distributing lower temperature water in an ice storage system. However, this is not appropriate with a chilled water or eutectic salt system.

Chilled water thermal storage has many advantages: it is easily interfaced with cooling plants, can be stored above ground in tanks or below ground in concrete pits, can provide uniform discharge temperature when properly stratified, has the lowest operating cost, and is easily controlled. Careful design is required to avoid temperature blending in the storage tank. The main disadvantage is that storage requirements are large.

Storage requirements for ice systems are smaller than chilled water systems because ice has a much greater cool storage capacity. The latent heat of fusion for water is 144 Btu/lb whereas the specific heat of ice is 1 Btu/lb-°F. Ice storage systems are available in packaged systems that can be readily coupled to refrigeration units. A disadvantage of ice storage systems is the difficulty in controlling uniform discharge temperatures, which will vary with discharge rate.

Eutectic salt storage systems use a phase change material that freezes at 42°F or 47°F. Similar to ice systems, these require less volume than chilled water storage (the latent heat of fusion is 41 Btu/lb). They have low standby losses and use standard water chillers. Standard temperature water chillers also operate more efficiently than ice builders.

There are three basic TES strategies:

- Full storage, where the storage system is sized to provide the total cooling load with no assistance from the cooling plant.
- Partial storage, where the storage system is sized so that cooling load is provided by a combination of chiller operation and storage draw-down. Partial storage systems minimize both chiller and storage capacities.
- Demand limited storage, where the cooling plant is shut down during peak periods and the storage system is sized to satisfy the cooling load during this period. This system is similar to the full storage system except that the number of hours the cooling plant is shut down is limited to utility on-peak (and possibly partial-peak) periods.

The West Valley Detention Center in San Bernardino County uses a Calmac thermal ice storage system serving a 1,200 cell pre-trial facility. The system capacity is 7,410 ton-hours, utilizing 39 tanks and three 465-ton chillers. The TES system meets the cooling demand of the entire facility during the day, and the chillers are programmed not to run during the daytime. The TES system does not have any significant operational or maintenance problems. Based on a 24-year life, life-cycle savings are estimated to be $1.3 million, resulting in a 6.4 year payback. The local utility, Southern California Edison, provided a $114,780 installation incentive.

The Placer County Juvenile Hall in Auburn has four ice storage tanks, each holding 1,620 gallons. Ice is produced by an air-cooled 100-ton chiller using ethylene glycol as the transfer medium. This facility has 70 beds.

Cogeneration Systems

> Recommendation:
> Consider cogeneration systems for large detention facility projects with central plants, particularly in areas with available natural gas, expensive electricity, and facilities with high thermal loads.

Cogeneration systems are engine/generators that produce electricity to reduce the site load and provide waste heat to displace the purchase of fuels, such as natural gas.

Cogeneration units reduce electricity purchases from the local utility and provide process heat that could be used for heating water to meet domestic loads. The magnitude of cost savings is a sum of energy and demand savings. Energy savings result from kilowatt hours (kWh) purchased each month. The value of the kWh may vary depending upon the time of day and utility.

Demand savings occur only when the cogeneration unit is operational during the hour of peak demand. Demand savings should not be projected for each month as the unit is subject to unscheduled downtime.

Gas purchased for the cogeneration system is usually available at a discounted cogeneration rate. To be eligible for this rate, cogeneration units must meet a certain level of energy efficiency as established by the federal government. Natural gas used by a boiler will use the standard gas rate schedule.

Cost Effectiveness

The cost effectiveness of a cogeneration system must be evaluated for each case because thermal loads, applicable utility rates, and engine emission requirements vary from one project to the next.

An important factor is whether standby charges must be paid to the utility to ensure electricity supply when the cogeneration unit is not operating. These charges can have a big impact on project cost effectiveness. Some cogeneration plants serve independent electrical circuits and avoid these standby charges, but be sure to check local regulations.

Design Guidelines

Several cogeneration technologies are available. Reciprocating engines are the traditional means to produce power. More recently, gas turbines and fuel cells have become available in sizes appropriate for cogeneration.

For reciprocating units, typical engine size is from 60 to 200 kW. These units use a spark ignited reciprocating natural gas engine that drives an electrical generator. Generally, fuel-oil fired systems are not used because exhaust emissions are unacceptable.

Gas turbines range from 30 kW to more than 230 MW. These work like a jet engine except that the hot combustion exhaust spins a turbine to produce electricity rather than propel an aircraft. Heat is recovered from the hot exhaust air after it passes through the turbine.

Fuel cells use means similar to a battery to produce electricity. They consist of two electrodes sandwiched around a catalyst and electrolyte. Hydrogen and oxygen are fed to either side of the sandwich and the catalyst causes the hydrogen to split into an electron and a proton. The proton passes through the electrolyte and the electron travels through an external wire (providing the fuel cell output). The proton and electron join with the oxygen on the other side to produce water. Hydrogen is typically created from natural gas in a fuel reformer.

The electricity generated by the cogeneration system is fed into the facility's grid. Synchronous generators can provide emergency power when the electrical grid is down. However, these generators are an expensive alternative to emergency generators. These cogeneration units still need to be connected to the electric grid, whereas, emergency generators do not. Also, the electricity produced from cogeneration units is used throughout the facility. However, the regulations require that emergency power be supplied to only specific systems in a facility. To achieve this, a cogeneration system would also have to be directly wired to these specific systems, thus adding to project expense. As a result facilities with cogeneration units must still include an emergency generator.

In a typical engine, heat is dumped through the radiator and out the engine exhaust. In a cogeneration engine, heat exchangers are used to capture this heat. They typically produce water at about 200°F.

This heat can be used at the central plant to provide some or all of the heat needed for space heating and domestic water heating. This displaces the combustion of natural gas in a boiler.

The maintenance of the system is usually contracted out to a service company for about $0.015 to $0.020 per kWh generated. This should cover complete maintenance including engine overhauls and replacement. The maintenance agreement should be tied to the amount of kWh generated and the demand charges paid to the utility, rather than to a fixed yearly fee.

Cogeneration systems operate only about 90 percent of the time. Down-time occurs as a result of planned maintenance and unscheduled outages.

In cogeneration systems of this type it is usually undesirable to generate more electricity than the site uses. Excess power could be exported to the utility. Depending on the contract terms, the site may not be fully reimbursed for excess electricity produced.

The cogeneration unit should be sized so that its thermal output is usually less than the site load. If the thermal output is greater the unit must be cycled or throttled, or heat must be dumped. The choice of how to handle the excess heat depends upon the utility rate schedules and the controls available for the unit.

Some utilities charge for standby capacity equal to the size of the cogeneration unit. This should be factored into the analysis for a correct picture of the potential savings. Utilities may charge for the cost of metering and protection equipment, as well as design services for interconnection with their lines.

The Sequoia Field Correctional Facility in Tulare County, a 130,000 ft^2 complex for 400 inmates, uses a 600 kW gas-fired engine cogeneration unit to provide heat for a 100-ton absorption chiller, a kitchen/laundry capable of serving 1,200 persons per day and one-half the electricity required to operate two 300-ton centrifugal chillers. No operational or maintenance problems reported, and the facility pays lower gas rates for the plant.

The R. J. Donavan Correctional Facility, located in San Diego and housing 4,600 inmates, has a 3,000 kW gas turbine with heat recovery boiler and an economizer. The heat recovery boiler can produce 18,000 lbm/hr saturated steam at 125 psig. The steam is used in bakery, kitchen, laundry, textile mill, and for heating the domestic hot water. Condensate from steam users is returned to the heat recovery boiler. The plant is reported to save over $500,000 per year.

Variable Speed Pumping

Recommendation:
Use primary/secondary or primary-only variable speed pumping on medium to large chilled water pumping systems.

Variable speed pump motor drives reduce pump motor energy requirements in central hot water, chilled water and condenser water systems by decreasing pumping horsepower relative to flow requirements.

Pumping flow rates are adjusted by varying the speed of the pump motor through a frequency inverter.

Two-way control valves in place of three-way valves are used to modulate flow through heating and/or cooling coils. A constant differential pressure is maintained near the end of the pumping system by varying pump speed.

Figure 34 shows variable speed pumping options.

Cost Effectiveness

Variable speed pumping is usually cost-effective for all but small applications. Installing a variable frequency drive (VFD) on a chilled water pumping system can reduce annual utility bills between $0.03 and $0.05 per square foot, with a simple payback of two to four years. Table 25 compares the cost-effectiveness of variable speed drive secondary pumps to constant speed primary pumps.

Design Guidelines

For small chilled water systems, constant speed pumping is more cost-effective than variable speed. Small systems serve only one chilled-water coil or a few small coils. Small systems typically have less than 5 coils, less than 100 gpm per coil, and less than 40 feet of distribution losses. Systems not meeting these criteria should use primary/ secondary or primary-only variable speed pumping. Primary-only variable flow systems will always cost less than primary/secondary. Primary systems will use less energy but are more complicated to design and operate for two reasons:

- Complexity of bypass

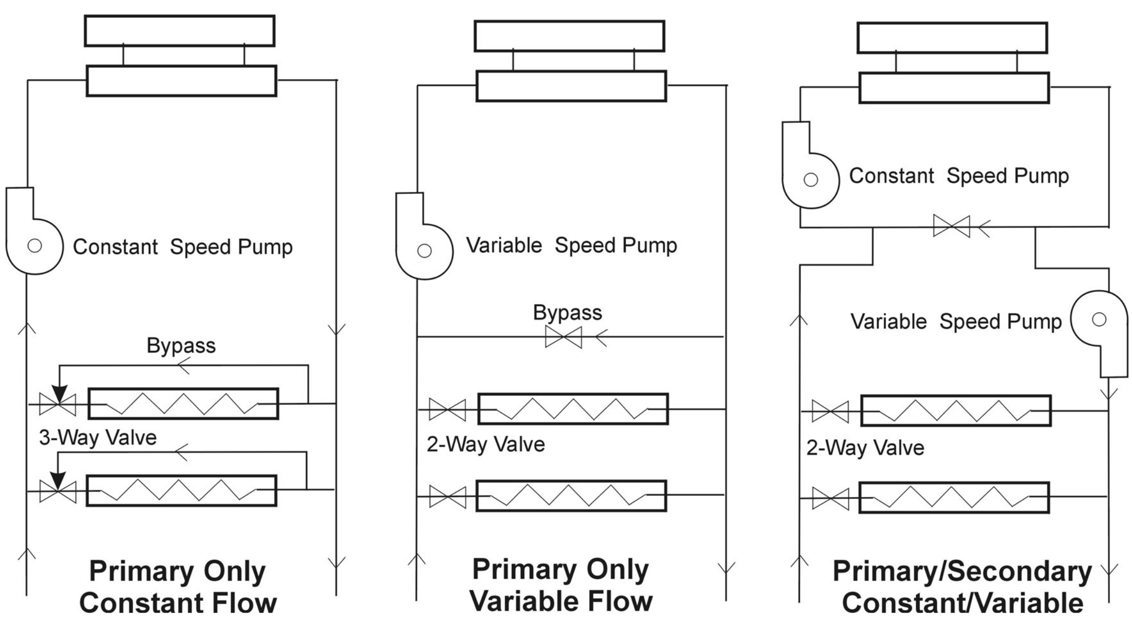

Figure 34 Variable Speed Chilled Water Pumping Options

control. Unless the chiller plant has a large number of chillers, some type of bypass valve will be required in order to ensure that minimum flow rates are maintained through operating chillers. If flow rates become too low, chillers will automatically shut down to prevent damage. If flow rates are maintained too high, energy is wasted.

- Complexity of chiller staging. If one or more chillers are running and another one is turned on, the flow through the active chillers can suddenly drop causing them to shut down or freeze up. Thus, active chillers must first be temporarily unloaded, the new one slowly brought on line, and finally all chillers slowly ramped up.

Given these considerations, primary-only systems are most appropriate for:

- Plants with many chillers (e.g., more than three) and with fairly high base loads where the need for bypass is minimal or nil and flow fluctuations during staging are small due to the large number of chillers; and
- Plants where there are on-site operators who understand the complexity of the controls.

A primary/secondary system is probably a better choice for buildings where fail-safe operation is essential or an experienced operator is unavailable.

If using a primary/secondary pumping system for a large plant serving multiple buildings, consider a distributed pumping system. This strategy moves the secondary pumps from within the plant and locates them remotely nearer to the loads they serve. On a large system, the secondary pumps would be located in the building being served rather than the central plant. The pumps are sized for the pressure drop needed to move the water from the common pipe to their most remote coil within the building and back to the common pipe. Significant pump energy savings can be achieved with this strategy.

For primary-only or primary/secondary, it is important to select cooling coils for the highest delta T that is practical (15°F to18°F) and be aware of “Low Delta T Syndrome” and how to avoid it through careful design and proper operation.

When using VFD in conjunction with chilled water supply temperature reset, use a clamp on the maximum speed of the pumps.

Table 25 Variable Speed Secondary Pumps (Compared to Constant Speed Primary-Only)

	First Cost Premium		Annual Energy Savings		Simple Payback Period	Life-Cycle Cost Savings	
	($/ft²)	($/ton)	($/ft²)	($/ton)	(years)	($/ft²)	($/ton)
Variable Speed Chilled Water Pump							
Coast	0.07	44	0.034	20	2.2	0.27	157
South	0.10	44	0.047	20	2.2	0.36	154
Valley	0.12	44	0.047	18	2.5	0.36	132
Desert	0.10	44	0.032	13	3.3	0.21	90
Cold	0.09	44	0.025	12	3.5	0.16	81

Assumptions

1) Costs presented per square foot of facility floor area and per ton of system capacity.

2) Total installed cost estimates are $744/ton primary only, $788/ton primary/secondary with variable speed drive.

The 210 bed Tulare County Juvenile Detention Facility uses variable frequency drives for both chilled water and hot water secondary loops.

Variable frequency pump drives are used to modulate chilled water circulating loops in the West Valley Detention Center in San Bernardino County (a 670,000 square feet facility for 960 inmates). They have not experienced any major operational or maintenance problems.

High Efficiency Boilers

Recommendation:
Consider high efficiency pulse boilers for space heating and domestic hot water.

Standard power-vented boilers have combustion efficiencies of about 82 percent, while condensing boilers are currently available offering efficiencies over 96 percent. These condensing boilers use either forced combustion, blower supplies combustion air, or pulse combustion, blower needed only for ignition. Actual operating efficiencies for condensing boilers rarely exceed 90 percent for space heating boilers due to the relatively high inlet water temperature.

Figure 35 compares boiler efficiency to inlet water temperature.

Pulse boilers are similar to an internal combustion engine in that they burn charges of air and gas mixture in rapid succession. With each pulse, a new charge of combustion air and fuel is drawn into the chamber through a Teflon flapper valve by the momentum of the exhaust air. Combustion pressure forces the hot exhaust air through the heat exchanger and out the exhaust pipe.

Cost Effectiveness

For sizes up to about 500,000 Btu/hr, condensing boilers cost between 30 and 60 percent more than standard efficiency units. For larger boilers, the cost premium is greater. Fuel savings are about 12 percent. The simple payback period for a condensing boiler is about five to eight years ($0.23 to $0.35 per square foot incremental cost, and $0.04 to $0.08 per square foot annual savings). Table 26 shows the cost-effectiveness of high efficiency boilers in various climate zones.

Design Guidelines

Atmospheric boilers, the least expensive to install, are rarely used in detention facilities. This is because combustion efficiency is only about 75 percent.

Pulse boilers are available in hot water or steam models and in natural gas and propane versions.

Consider using several smaller modular boilers rather than a single large boiler to improve overall plant efficiency at low loads.

Condensing boilers produce acidic condensate that is corrosive to some materials such as steel or iron. Make

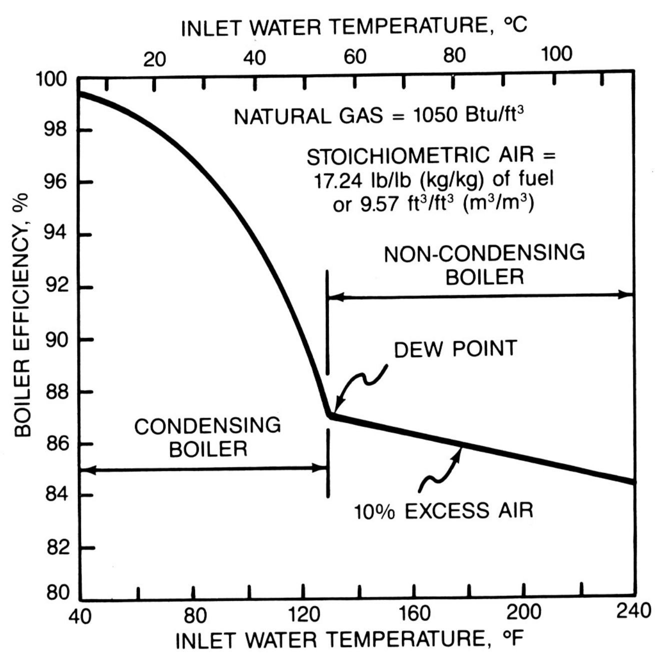

Figure 35 Boiler Efficiency (Reprinted with permission of the American Society of Heating, Refrigerating and Air Conditioning Engineers)

Table 26 Boilers

	First Cost Premium ($/ft²)	Annual Energy Savings ($/ft²)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)
High Efficiency Boiler				
Coast	0.23	0.041	5.6	0.18
South	0.29	0.044	6.6	0.15
Valley	0.29	0.046	6.2	0.17
Desert	0.35	0.045	7.6	0.11
Cold	0.35	0.076	4.6	0.41

Assumptions

1) Costs presented per square foot of facility floor area.
2) Installed cost estimates are $35/kBtuh for baseline, $52/kBtuh for a high efficiency boiler.
3) Efficiency improves from 0.80 to 0.94.

sure to account for proper condensate drainage and follow manufacturers specifications for exhaust flue design when specifying a condensing boiler.

The Todd Road Jail in Ventura County installed a 90 percent efficient pulse boiler to provide space conditioning and hot water for a laundry facility.

The Rio Consumnes Correctional Facility in Sacramento County also uses a natural gas fired pulse boiler.

> Recommendation:
> Use high-efficiency, water-cooled, variable speed chillers. Use chiller heat recovery if there is a reliable hot water demand.

After the decision is made to go with a central plant system, there are a number of chiller-related decisions with significant energy implications. One of the first decisions is air-cooled versus water-cooled chillers. When considering the cooling tower and condenser water loop, water cooled chillers cost more but are more energy efficient. Another critical decision is chiller type. Choices include electric (centrifugal, screw or scroll), gas-fired (engine-driven or double effect absorption), and steam absorption. Table 27 shows recommended chiller types based on the needed size. There are also decisions about how many chillers, what sizes, how they will be staged, efficiency levels, part-load control options, and heat recovery. Table 28 shows the efficiency of various chillers.

Cost Effectiveness

Many factors affect operating costs for a chilled water plant, and the best choice of type, size, efficiency and controls is difficult to generalize. Most California facilities experience varying cooling loads over the course of the year, and a variable speed drive (VSD) chiller will be cost effective. Table 29 shows that the incremental cost of an efficient chiller will pay off within about five years and a variable speed chiller in about 7 years.

Design Guidelines

Air-Cooled versus Water-Cooled. As a general rule, air-cooled chillers are more cost-effective if the chiller plant is less than 300 tons and water-cooled are more cost-effective at or above 300 tons.

Chiller Type. The best choice among electric, gas, and steam chillers, or some combination thereof, is largely site specific. If a reliable source of free or very low cost steam is available on site, then steam absorption makes the most sense.

Gas versus electric or hybrid gas/electric will depend on utility rates. Gas-fired chillers can cost two times more than electrically driven machines and will require a larger cooling tower and condenser water pump. Gas engine chillers are more energy efficient than absorption machines and have high temperature heat readily available for recovery but are more maintenance intensive than absorption machines. The most cost-effective type of electric chiller is primarily a function of chiller size. General decision guidelines are listed in Table 27.

Number of Chillers. As a general rule:

- If the peak chilled water load is less than 300 tons then a single chiller is usually most economical.
- If the load is between 300 and 1000 tons then use two chillers. This offers better low load capability and operating efficiency and offers some redundancy should one of the chillers fail.
- If the load is between 1000 and 3600 tons then use three chillers.
- If the load is over 3600 tons then use multiple

Table 27 Recommended Electric Chiller Types

Chiller Size	Recommendation
<= 100 tons	1st choice: scroll 2nd choice: screw 3rd choice: centrifugal
100 – 300 tons	1st choice: screw 2nd choice: scroll 3rd choice: centrifugal
> 300 tons	1st choice: centrifugal 2nd choice: screw

chillers of around 1200 tons each. Chillers tend to become more cost-effective as they approach 1200 tons in size and then less cost-effective over 1200 tons.

Having one smaller or pony chiller, versus two or more equally sized chillers, can improve part-load efficiency of the plant. However, some operators prefer keeping the machines the same size due to familiarity and parts interchangeability.

Unloading Mechanism. Centrifugal chillers typically use inlet vanes to control the chiller output at part-load. The use of hot gas bypass as a means to control the chiller at very low loads should be avoided. This strategy results in significant energy penalties. Using a variable speed drive instead of inlet vanes allows the compressor to run at lower speed at part-load conditions, thereby reducing the chiller energy use (kW/ton) more than inlet vanes. The energy savings from a VSD chiller can be quite significant if the chiller operates many hours at low load. To capture the potential savings of VSD chillers, it is important that the condenser water temperature is reset when ambient conditions are below design conditions. This can be accomplished either by using a fixed setpoint (e.g. 70°F) that is below the design condenser water temperature (e.g. 85°F) or using wetbulb-reset control, which produces the coldest condenser water the tower is capable of producing at a particular time.

Chiller Efficiency The ratings in Table 28 should be considered as upper bounds. Lower efficiencies are available and are often the lowest lifecycle cost option.

Heat Recovery Chiller. Heat rejected from the condenser of a chiller can be recovered and used for preheating domestic hot water by routing the condenser water through a double-wall heat exchanger that is either an integral part of a storage tank or is remotely located with a circulation pump to the storage tank. Heat recovery chillers are typically used only for a portion of the total cooling load due to the need to match hot water and cooling loads and because of the lower efficiency of heat recovery chillers. Heat recovery chillers are not typically piped in parallel with other chillers but rather are either piped for “preferential” loading or in series with other chillers, allowing the cooling load on the heat recovery chiller to be matched to the hot water load.

The energy savings from

Table 28 Recommended Chiller Rated Efficiency

Condenser Type	Compressor Type	Min Tons	Max Tons	Recm'd kW/Ton	Recm'd IPLV	Recm'd C.O.P.
Water cooled	Scroll	1	80	0.79	0.78	
Water cooled	Screw	1	150	0.76	0.70	
Water cooled	Screw	151	300	0.72	0.70	
Water cooled	Screw	301	& up	0.64	0.61	
Water cooled	Reciprocating	1	80	0.84	0.75	
Water cooled	Reciprocating	81	& up	0.82	0.75	
Water cooled	Gas Engine	501	2000			1.80
Water cooled	Absorption (SE)	150	1000			0.65
Water cooled	Absorption (DE)	150	1000			1.13
Water cooled	Centrifugal	1	150	0.62	0.62	
Water cooled	Centrifugal	151	300	0.60	0.61	
Water cooled	Centrifugal	301	& up	0.56	0.56	
Air cooled	Scroll	1	80	1.25	1.10	
Air cooled	Screw	1	& up	1.21	1.00	
Air cooled	Reciprocating	1	& up	1.15	1.15	
Air cooled	Centrifugal	1	& up	1.30	1.30	

* See Appendix C for definitions of IPLV and COP

chiller heat recovery are reduced when using economizers (air-side or water-side) because chillers are often not needed when the weather is mild or cold. However, given the large, constant domestic hot water load of detention facilities, chiller heat recovery is still likely to be cost-effective. Chiller heat recovery cannot eliminate the need for a DHW boiler but it can eliminate the need for some of the cooling towers at a site.

Chiller Staging. For a plant composed of single-speed chillers, control systems should be designed to operate only the chillers needed to meet the load. A plant composed of variable-speed chillers should attempt to keep as many chillers running as possible, provided they are all operating at above approximately 20 to 35 percent load. For the typical variable-speed chiller plant, it is more efficient to run three chillers at 30 percent load than to run one chiller at 90 percent load. The use of hot gas bypass at very low loads should be avoided since this strategy results in significant energy penalties.

Commissioning

In order for chillers to operate efficiently, they must be properly commissioned. Part of this process is making sure that sensors are specified and properly calibrated. Important sensors include those associated with chilled water flow, chilled water supply and return temperatures, and chiller electric demand.

Sensor data should be permanently stored by the energy management system (EMS) and easily visualized graphically. Not only is this data valuable for insuring that the design intent is met in the construction process, but also for maintaining energy efficiency over the life of the chiller(s). For example, by monitoring the approach temperatures in the condenser and evaporator heat exchangers, one can detect when maintenance needs to be scheduled. As the heat exchanger surface becomes fouled, the approach temperature increases. If maintenance is scheduled too often, maintenance resources are wasted. If maintenance is scheduled infrequently, energy is wasted.

The Sequoia Field Correctional Facility in Tulare County, uses a gas-fired cogeneration unit to provide heat for a 100-ton absorption chiller.

Ventura County, Todd Road Jail uses an energy efficient electric chiller rated at 0.55 kW/ton and a double effect gas absorption chiller that operates during summer on-peak periods.

At the Tulare County Juvenile Detention Facility the chiller is rated at 0.52 kW/ton (electric centrifugal) and the system employs temperature reset controls.

At the Santa Ana Police Facility, condenser water from a small chiller preheats water using a plate and frame heat exchanger that replaces the cooling tower. The system provides about 10 degrees of heating.

Table 29 VSD Chiller Cost Effectiveness

	First Cost Premium		Annual Energy Savings		Simple Payback Period	Life-Cycle Cost Savings	
	($/ft²)	($/ton)	($/ft²)	($/ton)	(years)	($/ft²)	($/ton)
Variable Speed Chilled Water Pump							
Coast	0.07	44	0.034	20	2.2	0.27	157
South	0.10	44	0.047	20	2.2	0.36	154
Valley	0.12	44	0.047	18	2.5	0.36	132
Desert	0.10	44	0.032	13	3.3	0.21	90
Cold	0.09	44	0.025	12	3.5	0.16	81

Assumptions

1) Costs presented per square foot of facility floor area and per ton of system capacity.
2) Total installed cost estimates are $744/ton primary only, $788/ton primary/secondary with variable speed drive.

High Efficiency Cooling Tower

> Recommendation:
> For systems with a cooling tower, select an oversized unit with induced-draft axial fan, low approach temperature and variable speed fan control.

An induced-draft cooling tower with axial (propeller) fan is more efficient than a forced-draft unit with centrifugal fans or a fluid cooler (closed-circuit cooling tower). Centrifugal fans use twice the energy of axial fans at roughly the same cost. Therefore, every effort should be made to accommodate a propeller fan tower before considering a centrifugal fan tower.

In addition, an oversized cooling tower provides savings because chillers operate more efficiently with cooler condenser water. An oversized tower should have variable-speed or two-speed fan controls to efficiently control water temperature. Pumps should also be staged or have variable speed controls to vary flow with load.

Table 30 lists some of the design tradeoffs to consider in choosing a cooling tower such as energy efficiency, noise, and cost.

Cost Effectiveness

Increasing the size and efficiency of a cooling tower is generally cost effective, providing a four to seven year payback (Table 31). Annual energy savings range from $0.01 to $0.04 per square foot, and incremental costs are between $0.08 and $0.12 per square foot depending on climate. In other terms, incremental costs are $45 per ton of central plant cooling capacity and annual energy savings range from $6 to $13 per ton.

Design Guidelines

Tower Fan Speed Control. Two-speed (1,800 rpm/900 rpm) or variable speed fan control is always more cost effective than single speed fan control. For plants with multiple towers or multiple cells, provide two-speed or variable-speed control on all cells, not just the “lead” cells. The towers are most efficient when all cells are running at low speed rather than some at full speed and some off. For instance, two cells operating at half speed will use about 15 percent of full power compared to 50 percent of full power when one cell is on and the other is off.

Variable speed drives are preferred over two-speed drives. Additional advantages are more energy savings, better control, lower noise level, less water consumption and less chemical treatment cost.

Tower Over Sizing. The tower and fill can be

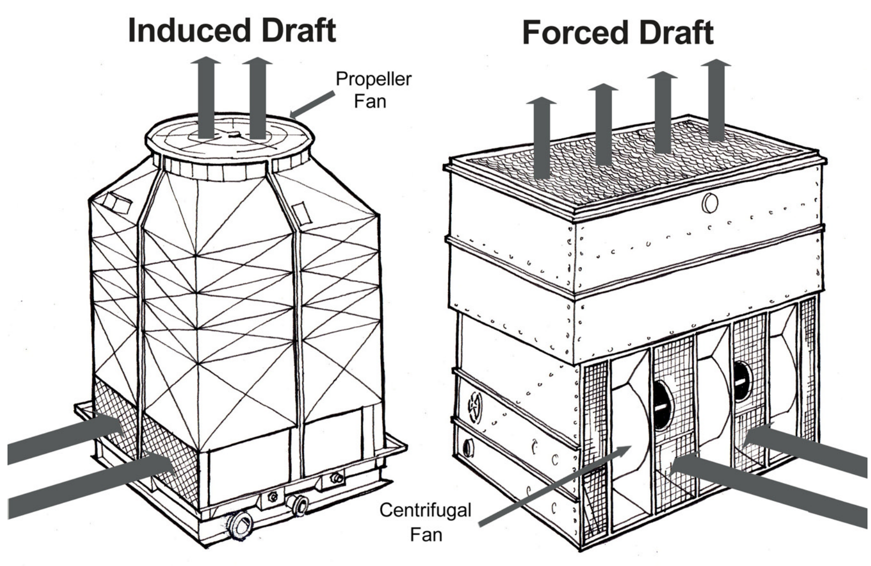

Figure 36 Cooling Towers

Table 30 Cooling Tower Design Considerations

	Energy	Noise	Height	Chiller Fouling	Cost	Application
Packaged induced draft, axial fan	Lower	Higher	Higher	Higher	Medium	Best for most plants
Field-erected induced draft, axial fan	Lowest	Higher	Higher	Higher	Higher	Very large plants
Forced draft, centrifugal fan	Higher	Lower	Lower	Higher	Lower	Best if noise or height constrained or large external static pressure (e.g. tower located indoors)
Closed circuit evaporative cooler, axial fan	Higher	Higher	Higher	Lower	Highest	Appropriate for heat pumps, not most chillers
Closed circuit evaporative cooler, centrifugal fan	Highest	Lower	Lower	Lower	Highest	Appropriate for heat pumps, not most chillers
Spray towers	Lowest	Lowest	Higher	Higher	Lowest	Seldom used due to high maintenance and variable condenser water flow

oversized to reduce pressure drop, thereby allowing the fan to be slowed down, which reduces motor power. Tower heat transfer area should be oversized to improve efficiency to at least 60 to 80 gallons per minute/horsepower at Cooling Tower Institute (CTI) conditions. Tower efficiency as defined in ASHRAE Standard 90.1-1999 is the ratio of the maximum tower flow rate (gpm) to the fan motor horsepower (hp) at standard CTI rating conditions (95^o F to 85^o F at 78^o F set bulb). Standard efficiency is about 35-40 gpm/hp.

There will be some added cost to oversize the tower and to accommodate the larger tower footprint and weight. These would be outweighed by energy savings.

A larger tower can also produce cooler water, allowing chillers to run more efficiently. Selecting towers for a four or five degree approach will generally be cost effective relative to a more typical ten degrees. Cooling towers are available with as low as 3 degree approach temperature, but the tower cost increases as the degree of approach drops. A life cycle cost analysis should be performed to compare these extra costs to the energy impact on tower, chiller, and pumps.

Table 31 Cooling Tower

	First Cost Premium		Annual Energy Savings		Simple Payback Period	Life-Cycle Cost Savings	
	($/ft²)	($/ton)	($/ft²)	($/ton)	(years)	($/ft²)	($/ton)
Efficient Cooling Tower							
Coast	0.08	45	0.014	8.3	5.4	0.06	38
South	0.11	45	0.029	12.5	3.6	0.19	80
Valley	0.12	45	0.035	12.9	3.5	0.23	84
Desert	0.11	45	0.025	10.7	4.2	0.15	62
Cold	0.09	45	0.013	6.2	7.3	0.03	17

Assumptions

1) Costs presented per square foot of facility floor area and per ton of system capacity.
2) Efficiency improvement from 37.5 gpm/hp to 75 gpm/hp.
3) Size increase from 8°F approach to 4°F approach.
4) Total installed cost estimates are $133/ton baseline, $178/ton high efficiency.

High Efficiency Packaged Equipment

Recommendation:
If packaged equipment is chosen (versus no cooling, evaporative cooling, or central plant), then select models with high energy efficiency ratio (EER) and integrated part load value (IPLV) ratings. Use evaporative precooling of outside air, and evaporative pre-cooling of condenser air or evaporatively cooled condensers, as appropriate.

Packaged rooftop units that have significantly higher seasonal energy efficiency ratio (SEER), EER and IPLV ratings than minimum Title 24 efficiencies are readily available, often at little or no incremental cost.

Evaporative cooling can be combined with packaged rooftop cooling by adding direct and/or indirect coolers onto the outside air intake of the packaged unit or it can be integrated directly into the mixed air stream (outside and return) of the packaged unit. Evaporative cooling reduces the load on the direct expansion (DX) cooling coil, allowing the compressor size to be reduced, and peak power to be reduced.

Water can also be sprayed into the air stream entering the condenser section of the packaged unit (evaporative pre-cooled condenser) or directly onto the condenser coils (evaporatively cooled condenser). This reduces the condenser temperature and increases the packaged unit's efficiency and capacity.

Recommendations in this section apply to both package single-zone and package variable air volume (VAV) equipment.

Cost Effectiveness

High efficiency package units cost about ten percent more than standard efficiency models and have paybacks of around three to four years in warm climates. Indirect evaporative cooling adds about 20 percent to the base unit cost and can pay for itself in about four to seven years. Indirect/direct evaporative cooling will add about 40 percent and will also pay for itself in about four to seven years. Evaporative pre-cooled condensers add about ten percent to the cost of the equipment and can pay for themselves in two to three years. Finally, a combination of high EER, indirect/direct evaporative cooling and evaporative pre-cooled condensers will almost double the cost of the packaged equipment, but it will cut cooling costs in half and pay for itself in five to ten years. Table 33 summarizes the cost-effectiveness of package units by climate zone.

Design Guidelines

Combination evaporative and DX cooling makes economic sense in certain climates and for packaged units over a certain size. Direct and/or indirect evaporative cooling should be considered for packaged units over:

- 20 tons in South Coast (Climate Zones 6 - 10)
- 15 tons in Central Valley (Climate Zones 11-13)
- 10 tons in Desert (Climate Zones 14, 15)

Evaporative pre-cooled condenser is generally cost-effective for units over ten tons in Valley and Desert climates (Zones 11-15). Evaporative condenser is generally cost-effective for units over 75 tons in Valley and Desert climates. An evaporative pre-cooled condenser should not be used simultaneously with an evaporative condenser.

Table 32 Recommended Efficiencies for Packaged Rooftop Equipment

Condenser Type and Equipment Size	Recommendation
Air Source < 65,000 Btu/hour	12.0 SEER
Air Source 65,000 – 135,000 Btu/hour	10.3 EER
Air Source 135,000 – 240,000 Btu/hour	9.7 EER
Air Source > 240,000 Btu/hour	10.0 EER
Water/Evap. Source < 65,000 Btu/hour	12.1 EER
Water/Evap. Source 65,000 – 135,000 Btu/hour	12.0 EER
Water/Evap. Source > 135,000 Btu/hour	11.0 EER

Table 33 Packaged Equipment Upgrades

Space Type/Climate	First Cost Premium ($/ft²)	First Cost Premium ($/ton)	Annual Energy Savings ($/ft²)	Annual Energy Savings ($/ton)	Simple Payback Period (years)	Life-Cycle Cost Savings ($/ft²)	Life-Cycle Cost Savings ($/ton)
Living/Valley							
High Efficiency	0.16	70	0.06	24	2.9	0.40	172
Indirect Evaporative Cooling	0.33	140	0.08	34	4.2	0.46	196
Indirect/Direct Evaporative	0.66	280	0.15	65	4.3	0.88	374
Evaporatively Precooled Condenser	0.14	70	0.07	36	1.9	0.59	290
All Measures	1.13	560	0.19	93	6.0	0.75	370
Living/South							
High Efficiency	0.13	70	0.04	19	3.7	0.23	117
Indirect Evaporative Cooling	0.27	140	0.05	25	5.5	0.22	114
Indirect/Direct Evaporative	0.54	280	0.08	43	6.6	0.28	145
Evaporatively Precooled Condenser	0.12	70	0.04	23	3.1	0.27	158
All Measures	0.95	560	0.10	60	9.4	0.06	38

Assumptions:

1) Base case efficiency = 8.5 EER. High efficiency = 10.0 EER
2) Indirect evaporative cooler effectiveness = 60 percent
3) Direct evaporative cooler effectiveness = 65 percent
4) Evap cooler electric power = 0.001 bhp/cfm
5) Evap pre-cool condenser rated effectiveness = 80 percent

Evaporative/DX cooling can be used with an evaporative pre-cooled condenser or an evaporative condenser.

Duct Sealing and Insulation

> Recommendation:
> Create strong and long-lasting connections by mechanically fastening all duct connections and using mastic to seal connections and transverse joints (those perpendicular to airflow).

Duct leakage has a big impact on system efficiency and capacity. Studies of residential systems show that 20 to 30 percent loss is common. Similar problems exist in commercial duct systems.

Other studies have shown that some types of pressure-sensitive tape fail quickly in the field. Therefore, duct-sealing systems must be specified carefully for longevity as well as strength.

Depending on duct location, insulation also plays a critical role in ensuring system efficiency and capacity. Title 24 requires a minimum of R-4.2 insulation on all ducts carrying conditioned air unless the ducts are located within conditioned space.

Cost Effectiveness

Using mastic for duct sealing may increase material costs, but many find that labor costs drop compared to sealing with tape. Therefore, good duct sealing should not have a significant cost impact.

Careful duct sealing and insulation application will allow use of smaller cooling and heating equipment or at least allow the use of smaller safety margins in sizing calculations. Lower equipment cost may result.

Design Guidelines

Do not rely on sealants, such as tape or mastic, to provide a mechanical connection. Specify screws, draw bands, or other mechanical fastening devices.

As a first choice, use mastic to seal all connections and transverse joints. Mastic is a liquid applied sealant that can also be used together with a mesh or glass fiber tape to provide added strength or to span gaps of up to about ¼ inch. Specify a mastic in a water-based solvent with a base material of polyester/synthetic resins free of volatile organics.

If choosing pressure-sensitive tape as a sealant, specify foil-backed tape with 15-mil butyl adhesive. Butyl tape has been found to have greater longevity in the field. Use of tape with rubber or acrylic adhesive should be avoided.

Flexible ducts must be mechanically fastened with draw bands securing the inner and outer plastic layers to the terminal boot. Specify that the draw bands be tightened as recommended by the manufacturer using an adjustable tensioning tool.

6. Other Considerations

This chapter presents information about transformers, operation and maintenance, and commissioning.

Detention facilities typically have a number of transformers. Transformers are used to reduce the voltage of electricity received from the utility to levels that can be used by the facility to power lights, computers and other electrical equipment.

Most commercial transformers have efficiencies exceeding 95 percent. However, as transformers operate 24 hours per day, 365 days per year, even a slight gain in efficiency can mean substantial savings in electricity bills. This section will discuss the factors to consider in proper size of transformers and the potential life cycle cost savings associated with purchasing energy efficient transformers.

Once the energy saving measures described in this guidebook have been installed, proper operation and maintenance of those measures are needed to ensure that the energy savings and other benefits will be sustained. Without an effective maintenance program, it is estimated that equipment operations can degrade and energy cost could increase by 15 to 30 percent annually. This section will discuss some of the elements of an effective operation and maintenance program.

Equipment/building commissioning is a process for ensuring that the installed equipment operates and continues to operate according to its designed intent. The process of commissioning starts in the planning stages and continues until after the facility is occupied.

The commissioning agent can be a specialized contractor hired by the facility owner or one that is part of the general contractor's team. The commissioning agent oversees equipment tests to ensure that equipment meets specific performance goals based on the design criteria in the construction documents. These tests and the subsequent modifications by the contractor ensure that the tested equipment meets the performance goals and will yield the projected savings and benefits. This section will discuss the commissioning steps at the pre-construction, construction, and post-construction phases.

Appendix B provides additional information sources for transformers and commissioning.

Transformers

> Recommendation:
> Select a transformer that operates most efficiently at the estimated average KVA load of the facility.

Transformers are used to step down the incoming high voltage from the electric utility electricity to lower levels. The main transformer lowers the voltage to 480 volts. A number of smaller transformers reduce the voltage from 480 volts to 120 volts so that the electricity can be used to power lights, computers and other electrical equipment.

All the electrical energy used in a facility has to go through one or more transformers. Most commercial/industrial transformers are at least 95 percent efficient. However, because transformers operate constantly, any increase in efficiency can result in substantial energy savings.

The following are the main factors for minimizing transformer losses:

- **Maximum demand**: The main transformer rating must exceed the maximum possible electrical load, measured in kVA, of the facility.
- **Average annual electrical load**: Select transformers that operate most efficiently at the estimated average kVA load, typically 30 to 50 percent.
- **Power factor**: The kVA load on the transformer depends on the active load and the reactive load. A lower power factor load can load the transformer beyond its rated capacity, resulting in higher winding temperatures and tripping of the transformer off line. For facilities with a low power factor, using automatic or manually switching capacitor banks is a better option than using a transformer with higher kVA rating.
- **Future expansion plans**: Select transformers with sufficient capacity to meet the future load requirements of the facility, without compromising efficiency at the expected initial load.
- **Core losses in the transformer**: Select transformers with minimum core losses. Core losses are independent of load and occur all the time as long as the transformer is charged.
- **Winding losses at full load**: Winding losses are proportional to the square of the load. Therefore, at full load these losses are very high. If a transformer will often operate at full loads, then select a transformer that has minimum winding losses in addition to low core losses.

The efficiency of a transformer depends on the load. A transformer with minimum core losses is always recommended because these reduced losses will save energy 24 hours a day, 365 days a year. At lower loads, core losses constitute a major percentage of transformer losses. If a transformer is expected to run at higher loads, select one with minimum core and winding losses. To minimize core and winding losses the most optimum load factor is 30 to 50 percent.

The efficiency versus load graphs of this section provide examples of the efficiency of different transformer types.

- Transformer 1 (Figure 37) is an energy efficient unit. This unit has lower core losses compared to Transformer 2. The efficiency is high in the 30 to 50 percent load factor range. At loads greater than 50 percent, the efficiency drops due to higher winding losses. This type of transformer is best suited when the load factor is between 30 to 50 percent.

- Transformer 2 (Figure 38) is an energy efficient unit. This unit has lower winding losses than transformer 1. The efficiency curve is flatter at the higher load factors (e.g., greater than 50 percent) than transformer 1. The efficiency is also higher than transformer 1 when the load varies above 30 percent since the efficiency does not decrease as much beyond the 50 percent load range.

The National Electrical Manufacturers Association (NEMA) publishes the TP-1 standards for transformers. Complying units meet minimum transformer efficiencies at 35 percent loading. However, transformers are available with higher than NEMA recommended efficiencies. In some cases these efficiencies exceed 99.5 percent.

Once a transformer is selected, it is rarely replaced since its operating life is typically 25 to 35 years. Therefore, selection of a high efficiency transformer will have long-term energy saving benefits and, the payback period is typically between one and five years.

The life cycle cost tables at the end of this section show the difference in life cycle cost for three transformers at two different sizes. The following are the types of transformers analyzed:

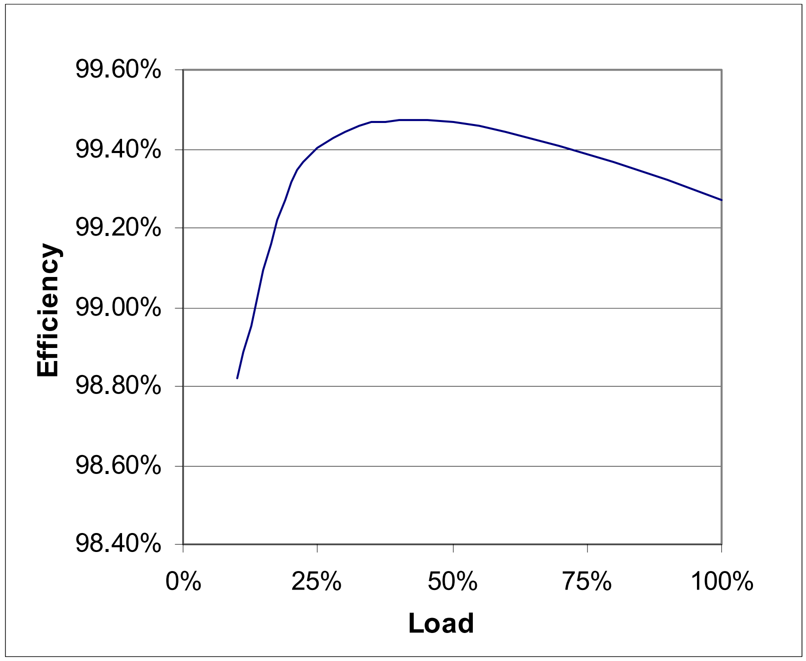

Figure 37 Transformer 1: Efficiency versus Load

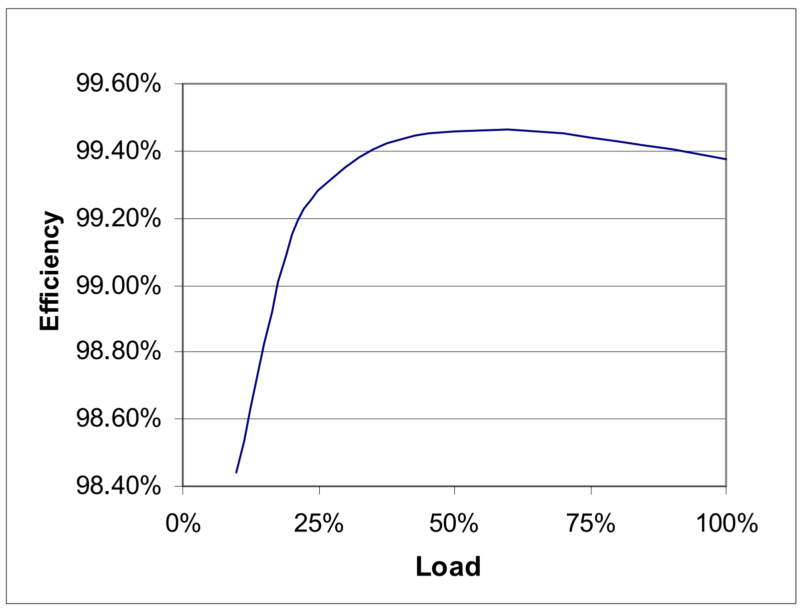

Figure 38 Transformer 2: Efficiency versus Load

- Conventional transformer with high core losses and high winding losses at full load
- Transformer 1 (EE 1) has low core losses and low winding losses at full load
- Transformer 2 (EE 2) has the lowest core losses and lowest winding losses at full load

The life cycle cost was calculated based on the following:

- Energy cost: $0.10/kWh
- Useful economic life: 30 years
- Discount rate: 6 percent
- Life cycle cost = initial cost + total annual kWh losses * 0.1 * (1.06^30-1)/(0.06*1.06^30)

Designers should calculate a realistic projected average and peak load of the facility and use this data to determine the best type of transformer for the facility. Designers should perform similar life cycle cost analysis to identify transformers that have minimum life cycle cost while meeting the peak load requirements of the facility. Appendix B contains additional information on energy efficient transformers.

Table 34 Life Cycle Costs of Various Transformers versus Load

Annual Average Load (KVA)	1000 KVA Transformer - Life Cycle Costs ($)			2500 KVA Transformer - Life Cycle Costs ($)		
	Standard	Transformer 1	Transformer 2	Standard	Transformer 1	Transformer 2
800	174,157	150,272	119,929	84,541	71,638	80,714
700	141,970	122,463	98,474	79,391	67,189	77,281
600	114,074	98,362	79,880	74,927	63,332	74,306
500	90,469	77,969	64,147	71,151	60,070	71,788
400	71,157	61,284	51,274	68,061	57,400	69,729
300	56,136	48,306	41,262	65,657	55,323	68,127
200	45,407	39,037	34,110	63,940	53,840	66,983
100	38,969	33,475	29,819	62,910	52,950	66,296
50	37,360	32,085	28,746	62,653	52,728	66,124
0	36,823	31,621	28,389	62,567	52,654	66,067
Assumptions:						
Initial Capital Cost	$9,500	$11,400	$14,100	$17,000	$19,000	$20,500

Transformer life = 30 years

Discount rate = 6%

Energy Price = $0.10/kWh

Maintenance

Recommendation:
Develop an effective maintenance program to ensure that installed equipment continues to operate efficiently and properly.

Without proper operation and effective maintenance, an energy efficiency project can be an economic, safety, or environmental failure and may not even serve its intended purpose. This section will discuss how to achieve an effective maintenance program and increased system reliability.

The following are the main elements of an effective maintenance program:

- Establish a budget for annual maintenance.
- Have qualified staff or experienced contractors provide the maintenance.
- Develop a preventative maintenance program. This will include periodic maintenance checks, and lubrication and filter replacements.
- Develop a predictive maintenance program that tracks equipment condition such as vibration, oil and refrigerant testing and equipment power consumption.
- Develop a system that will track work orders, performed maintenance and maintenance expense for each equipment.
- Develop maintenance procedures and checklists.
- Ensure that the maintenance staff has operation and maintenance manuals.
- Ensure availability of recommended spare parts and tools in the warehouse.
- Provide periodic, on-going training on optimizing equipment operations for the maintenance and facility staff.
- Hold periodic meetings with operation and maintenance staff.

Commissioning

Recommendation:
Have a comprehensive commissioning process that starts in the planning phase and continues through building occupancy.

Commissioning is the process of planning, inspecting, testing, modifying, and adjusting equipment and systems to ensure that the energy efficiency project performs as intended. An improperly commissioned equipment/ system has the following consequences:

- Costly and difficult operation
- Increased downtime and reduced comfort level for building occupants
- Increased equipment breakdowns and costly maintenance
- Increased health, safety, and environmental hazards for building occupants

A comprehensive commissioning process starts in the planning phase and continues through building occupancy. The following steps ensure effective project commissioning:

Pre-Construction Phase:

- Allocate two to three percent of the total project budget for commissioning
- Select a commissioning agent before developing the scope of work for the design team
- Include commissioning in the scope of work for the design team
- Have a commissioning plan that specifies the pre-functional and functional tests for all energy efficiency equipment in the construction document.
- State contractor participation requirements in the construction documents.

Construction Phase:

- Verify that all instruments have been calibrated
- Verify that construction complies with design specifications
- Ensure that equipment and instruments have proper tags and name plates
- Make modifications and adjustments to suit the project needs
- Adjust controls and set points for optimal operation
- Conduct a trial run of all equipment and systems
- Inspect equipment and system performance
- Perform pre-functional equipment testing as specified in the commissioning plan. Typically, the test is performed by the contractor under the direction of the commissioning agent.
- Keep track of all changes and set points
- Complete all protocols and documentation
- Train operating staff

Post-Construction Phase:

- Perform functional tests on energy efficiency equipment as specified in the commissioning plan. Typically, the test is conducted by the contractor and under the direction of the commissioning agent.
- Ensure proper initial operation. Redo the functional test until design requirements in the commissioning plan are met.
- Provide technical support and training during initial operation
- Ensure that appropriate staff understand equipment operating procedures, have operational checklists, drawings and operation and maintenance manuals and access to a contact person for technical support.

7. Technical Documentation

This chapter presents the assumptions and methods used to calculate the energy performance of the recommendations covered in this design guide.

The DOE 2.1E Computer Model

The public domain energy analysis computer program DOE 2.1, version E, was used to calculate the benefits of many of the energy efficiency opportunities. This computer program simulates the annual energy use of buildings and calculates variations in energy use for different building materials and systems.

Models of the typical building areas are developed by specifying the building construction types (i.e. walls, floors, roofs etc.), schedules of occupancy, lighting and equipment schedules (operating and fixture type), window and glazing types, and heating, ventilating and air conditioning (HVAC) systems.

Design variations are tested with a series of parametric runs. For example, the base case might be an administration building with single-glazed, tinted glass windows. A parametric run substituting double glass for the single glass would determine the potential energy savings of this conservation opportunity.

Building Analysis Model

Two generic building models are used to calculate the variations in annual energy use: one for the living areas and another for the office/administration areas.

Living Areas Model

The living area is modeled as a two-story housing unit consisting of three triangular dayrooms (Figure 39). Each triangular dayroom serves 32 cells, 16 on the ground floor and 16 on the mezzanine. The cells are against the outside wall of the living area and are stacked on top of each other. All 96 cells can be monitored easily from the apex of the triangle, where a control station is located. The model assumes three triangles for a total of 15,000 ft^2.

For the base case, the exterior walls of the living areas are modeled as fully grouted eight inch concrete block; the interior partition walls as fully grouted six inch concrete block; the cell windows as a clear glazed ¾ inch laminate of glass and polycarbonate; the roof of the

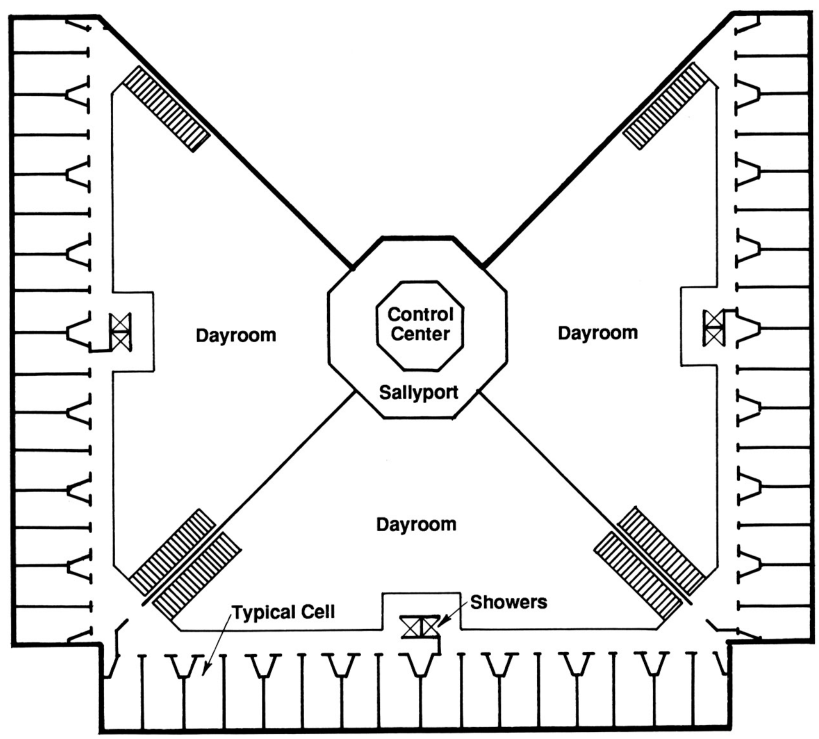

Figure 39 Living Area Model

cells are concrete with three inches of rigid insulation.

Small windows are assumed for each cell – about eight inches by three feet.

A single-zone constant volume air handler, supplied with chilled and hot water from a central plant, conditions the living area.

The lighting system consists of suspended fluorescent fixtures in the dayroom and ceiling mounted fixtures in the cells.

Table 35 indicates the estimated occupant densities for both the living and administrative areas used in this analysis.

Administration Areas

The administration building is operated 24 hours per day. The building size, used in the energy analysis model is 15,000 ft^2.

The administration building model consists of metal-framed walls with R-11 insulation and framed roof with R-19 insulation. Windows are single-pane tint with metal frames and take up 30 percent of the gross wall area. Floor is slab-on-grade without perimeter insulation.

The administration area is heated and cooled by variable air volume air handlers that are served by chilled and hot water from a central plant. The lighting fixtures throughout the building model are recessed fluorescent fixtures.

Table 36 Maximum Lighting and Equipment Power Densities

	Lighting (Watts/ft2)	Equipment (Watts/ft2)
Living Areas (Cells)	1.2	0.2
Administration	1.2	0.75

Detention Facility Complex

The model used to analyze the central plant energy efficiency opportunities (i.e. thermal energy storage, cogeneration, etc.) is a combination of one-half administration and one-half living area.

Construction Costs

Construction costs are based on published data when available including the 1996 Measure Cost Study, from the California Demand-Side Management Measurement Advisory Committee. If published data for a particular type of product was not available, information was gathered from suppliers, manufacturers and contractors. For those items with a range of prices the average cost is used.

Operating Schedules

In order to model the base case building and the various energy efficiency opportunities it was necessary to make assumptions regarding occupancy and operating schedules, light and equipment power densities, hot water use and HVAC schedules. The following tables and graphs show the occupancy, lighting, HVAC and hot water schedules.

Lighting and Equipment

The heat given off by lighting and equipment affects the balance point temperature of conditioned spaces, and therefore affects heating and cooling loads. The lighting levels used for the administration and office areas are the maximum levels allowed by the Title 24. Table 36 shows the lighting and equipment power densities used in the analysis.

The levels in Table 36 are the maximum power densities and are pro-rated by the schedules of operation. In the living areas, for example, only 40 percent of the lights are assumed to be on between the hours of midnight and 8 a.m.

Occupant Schedules

The number of occupants is important in analyzing the effectiveness of many of the energy efficiency

Table 35 Occupant Densities

	Occupant Density (ft2/person)
Living Areas	120
Administration	250

opportunities. Table 35 shows the occupant densities used in the analysis.

The energy analysis program uses schedules to pro-rate the number of occupants in the building at any particular time. The administration area operates on the same schedule seven days per week. The assumption is that the living areas will be occupied 100 percent of the time.

HVAC Operation

The air conditioning systems are assumed to be in operation 24 hours per day for the living and administration areas. Temperature set points in the living are 68°F for heating and 78°F for cooling. Set points in the administrative area are 70°F and 73°F.

Outside air ventilation rates vary from 50 percent fresh air for the living areas to approximately 10-15 percent for the administration and office areas.

Table 38 Air Handler Modeling Assumptions

	Administration	Living
System type	VAV	single zone
Economizer	Yes	Yes
Economizer setpoint	Return air T	Return air T
Fan SP (inches)	4.0	3.0
Fan control	VSD	constant
SAT setpoint	55 to 60, OA reset	55

Heating and Cooling Equipment

A central plant is modeled for the analysis of all the EEOs. The equipment used for the base case calculations include a hermetic centrifugal chiller, rated at 0.7 kW per ton, to provide chilled water for cooling, a boiler rated at 80 percent efficiency to provide domestic hot water and hot water for space heating.

Variable air volume air handlers are used in the administration areas, and constant volume air handlers provide conditioning for the living areas.

The base case system is relatively efficient, thus the estimates of energy savings are conservative.

Economic Performance

EEOs are evaluated on the basis of life-cycle cost, using a formula that takes into account annual operating costs, incremental construction costs and a series present worth factor.

Energy costs are calculated by DOE2.1E using Pacific Gas and Electric's E-19 time-of-use rate. This calculation accounts for electric demand charges and varying energy charges based on time of day. Pacific Gas and Electric's G-NR2 rate is used for natural gas.

Life-cycle cost is calculated using a series present worth factor of 10. That means annual savings of $1 are worth $10 today accounting for inflation and fuel escalation costs.

A positive result indicates a life-cycle cost savings, while a negative value would indicate that the present value of the energy savings is less than the cost premium and the investment is not cost-effective.

Expected energy savings and incremental construction costs are identified separately for each EEO to enable other measures of economic performance to be used by design professionals.

Table 37 Central Plant Modeling Assumptions

Chiller efficiency (kW/ton)	0.7
CHW primary pump head (ft)	30
CHW secondary pump head (ft)	80
CHW secondary pump control	VSD
Cooling tower approach (°F)	8.0
Cooling tower efficiency (bhp/ton)	0.08
CW pump head (ft)	40
Cooling tower fan control	2-speed
Boiler efficiency	0.80
Heating water pump head (ft)	80
Heating water pump control	fixed speed

Table 39 Climate Data

Location Climate zone	Coast Santa Maria CTZ05	Mountain Mt Shasta CTZ16	Valley Fresno CTZ13	Desert China Lake CTZ14	South Riverside CTZ10
Summer 1% Dry bulb	84	92	101	107	102
Summer 1% Wet bulb	64	67	72	68	71
Winter 1% Dry bulb	29	19	29	26	30
Summer 2.5% Dry bulb	89	100	106	98	79
Summer 2.5% Wet bulb	66	71	67	70	63
Winter 2.5% Dry bulb	23	31	28	32	31
Heating Degree Days (Base 65)	5610	2714	2459	2858	3073
Cooling Degree Days (Base 75)	11	73	520	1250	253
Yearly Average Sky Cover (Hours per Day)	3.6	3.8	2.7	2.2	4.0

The equation for calculation of life-cycle cost is:

ΔLCC =

SPWF x [(ΔAGC x Gas rate) + (ΔAEC x Elec rate)] - ΔC.

Where:

ΔLCC = Life-cycle cost savings

SPWF = Series present worth factor of ten to account for the estimated life of the building (or system), discount rates, fuel escalation rates, and other factors.

ΔAGC = Annual natural gas savings in therms.

Gas rate = The present fuel cost based on the G-NR2 rate schedule.

ΔAEC = Annual electricity savings in kWh.

Elec rate = The present electricity cost based on the E-19 rate schedule.

ΔC = Incremental construction cost associated with the ECO.

Climate Data

Five climate zones were selected to represent the coastal regions, the mountainous areas, the Central Valley, the desert and low desert. The cities selected for each zone are Santa Maria, Mount Shasta, Fresno, China Lake and Riverside.

Each weather data file used by the DOE 2.1 program contains one year (8,760 hours) of data for that particular location. The weather variables used by DOE 2.1 are dry bulb temperature, wet bulb temperature, atmospheric pressure, wind speed, wind direction, amount of cloud cover, cloud type, clearness number, ground temperature, humidity ratio, air density and specific enthalpy. Selective data from the hourly weather tapes used to analyze the energy efficiency opportunities are shown in Table 39.

Appendix A: Sample Scope of Work

This appendix contains two options for energy efficiency language to include in an architect's scope of work. The first is a performance approach, and the second is more prescriptive. The best choice depends on the local government's confidence in the capabilities of the design team.

An important consideration with either approach is that extra work may be required of the design team, and recommended measures may increase project cost. Therefore, it may be necessary to increase the budget or make room through eliminations. Ideally, however, the local government will recognize the benefit of operating cost savings and increase the construction budget from local funds.

Option 1.

Include an energy performance requirement in the architect's scope of work. Set a target of 20 to 30 percent better than minimum Title 24 requirements. Require the design team to perform simulation analyses at the design development and construction document phases to show that the target is achieved. One benefit to this approach is the flexibility given to the design team to determine their own design approach and to identify measures that are most cost effective. A potential disadvantage is that the architect may consider the performance requirement to be a significant risk, especially if the team does not have experience with energy analysis and efficient design.

If an architect is not yet selected, then it may be possible to link a portion of the design fees to the performance of the design. The designers would have a financial incentive to create an efficient design and would be compensated for the extra work involved in energy analysis.

Option 2

Include a complete list of tasks related to energy efficient design in the scope of work. With this approach the design team's responsibilities are clearer, but the architect has less flexibility in design approach. In this case, the language added to the scope of work could be as follows:

Work with the California Energy Commission and its consultant(s) in identifying, evaluating and modeling cost-effective elements and equipment for the PROJECT, with the goal being to reduce the life cycle costs of the PROJECT. Tasks to be completed by CONSULTANT, in consultation with the California Energy Commission and its consultant(s), include but not be limited to the following:

- Evaluate different building orientations and recommend an orientation that meets security and other requirements and optimizes energy efficiency.
- Evaluate various insulating materials, glazing, skylights, daylighting and thermal mass options and recommend those with minimum life cycle cost.
- Evaluate various lighting options that will meet the required or Illuminating Engineering Society recommended light levels for the specific space. In identifying options, CONSULTANT will ensure an energy efficient lighting layout while minimizing future maintenance cost. Specify the lighting level requirements and the designed lighting level in the design documents. Evaluate the life cycle cost of various lighting options together with other measures, such as skylights, daylight windows, and efficient lighting controls. Evaluate the life cycle cost of various lighting options. Recommend those lighting options with minimum life cycle cost

and that meets the requirements of the COUNTY.

- Evaluate various HVAC systems and equipment, including but not limited to high efficiency heating and cooling options, evaporative cooling, economizers, premium efficiency motors, variable speed drives, exhaust heat recovery, and controls to optimize energy usage. Evaluate the life cycle cost of various HVAC systems. Recommend those options with minimum life cycle cost and that meets the requirements of the County.
- Develop a commissioning plan to ensure that the building and its components perform according to the requirements specified in the design documents. At a minimum, the plan shall include commissioning procedures for each component, discussion of the pre-functional and functional tests, preparation of checklists and identification of commissioning agent.
- Include commissioning requirements in the bid documents.
- Include training requirements for operation and maintenance personnel in the bid documents.
- Include operating and maintenance procedures, manuals and requirements for providing checklists for operation and maintenance staff, in the bid documents.
- Discuss design options with California Energy Commission staff and its consultant(s) during the Architectural Program and Master Plan Development Phase. Continue the discussions through the Schematic Design, Design Development and Construction Documents Phases.

Appendix B: References

This appendix contains a partial list of references that could be consulted for additional information on some of the topics discussed in this document.

Project Management Handbooks

The Energy Commission has developed a series of handbooks designed to help public agencies and others implement energy efficiency projects. The following are currently available:

- *How to Hire an Energy Services Company*
- *How to Hire an Energy Auditor to Identify Energy Efficiency Projects*
- *How to Finance Public Sector Energy Efficiency Projects*
- *Energy Accounting: A Key Tool in Managing Energy Costs*
- *How to Hire a Construction Manager for Your Energy Efficiency Projects*
- *What You Should Know-Buying Electricity and Natural Gas in Today's Restructured Markets*
- *Guide to Preparing Feasibility Studies for Energy Efficiency Projects*

These documents can be downloaded through the Energy Commission's Web site: <www.energy.ca.gov/efficiency> or contact the Energy Commission at (916) 654-4008.

Technical Guides

ASHRAE Handbooks

-Fundamentals
-HVAC Systems and Equipment
-HVAC Applications
-Refrigeration

American Society of Heating, Refrigerating and Air Conditioning Engineers
(404) 636-8400

<www.ashrae.org>

These handbooks cover the principles and data needed for the design of heating, ventilating, air conditioning and refrigerating systems.

Lighting Handbook, Reference and Application

Illuminating Engineering Society of North America
(212) 248-5000

<www.iesna.org/>

This handbook includes explanations of concepts, techniques, applications, procedures, systems and definitions, task, clients, and diagrams.

Advanced Lighting Guidelines

California Energy Commission
(916) 654-5200

<www.newbuildings.org>

This document can be downloaded from the above referenced web site. This document contains information on advanced energy efficient lighting technologies. Guidelines are provided on lighting design practices, computer-aided lighting design, luminaires, and lighting systems, energy efficient and electronic ballasts, full-size fluorescent lamps, compact fluorescent lamps, conventional shape tungsten halogen lamps, compact metal halide and white high-pressure sodium lamps.

Non-Residential Manual for Compliance with Energy Efficiency Standards

California Energy Commission
(916) 654-5200

<www.energy.ca.gov/title24/index.html>.

The Energy Efficiency Standards for Residential and Nonresidential Buildings were established in 1978. The standards are updated periodically to consider and incorporate new energy efficiency technologies and methods.

Appliance Efficiency Standards

California Energy Commission
(916) 654-4064

<www.energy.ca.gov/appliances/documents/index.html>

In September 2000 the Legislature enacted AB 970 (Stats. 2000, chapter 329) in response to California's ongoing electricity crisis. In response to AB 970, the Commission published an initial proposal that contained new and revised efficiency standards for 20 appliances, some of which are not currently within the scope of the regulations. An update of the Title 20 filings are contained on the web site.

Commissioning Resources

Model Commission Plan and Guide Specifications

Portland Energy Conservation Incorporated
(503) 248-4636

<www.peci.org/cx/>

This web site contains information on building commissioning, operation and maintenance strategies and links to other organizations that have developed commissioning plans and specifications.

Software Programs

Building Life Cycle Cost (BLCC)

National Institute of Standards and Technology
(301) 975-6134

<www.eren.doe.gov/femp/techassist/softwaretools/soft>.

This software program, developed by the National Institute of Standards and Technology, provides an analysis of proposed capital investments that are expected to reduce long term operating costs of buildings or building systems. The program can be downloaded from their web site.

California Nonresidential Building Compliance Programs

California Energy Commission
(916) 654-5106

The Energy Commission approved the following energy analysis computer programs for Nonresidential Buildings:

– Energy Pro, Version 2.0

  Gabel/Dodd Associates
  (415) 883-5900
  www.energysoft.com

– Perform 98

  Please refer to the following Web Site for future software program updates:

  <http://www.energy.ca.gov/efficiency/computer_prog_list.html>

Energy Efficient Equipment

Energy Star Products

U.S. Environmental Protection Agency/ U.S. Department of Energy

<www.energystar.gov/>

This website provides information on energy saving products that will reduce energy use. Products include HVAC equipment, office products, lighting, roof products, transformers, appliances, water coolers, windows, and other energy using equipment.

Building Specifications for Energy Efficient Equipment

Eley Associates
(415) 957-1977

<www.eley.com>

As a contractor in the Energy Commission’s Public Interest Energy Research Program, Eley Associates is developing equipment specifications for energy efficient equipment. A draft version of the specifications is posted on their Web Site.

Appendix C: Glossary

This appendix contains a glossary of the terms used frequently throughout this document.

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE): ASHRAE writes standards that set uniform methods of testing and rating equipment and establish accepted practices for the heating, ventilating, air conditioning and refrigerating industry worldwide, such as the design of energy efficient buildings

British Thermal Unit (Btu): The standard measure of heat energy. It takes one Btu to raise the temperature of one pound of water by one degree Fahrenheit at sea level. For example, it takes about 2,000 Btus to make a pot of coffee. One Btu is equivalent to 252 calories, 778 foot-pounds, 1055 joules, and 0.293 watt-hours. Note: kBtu = 1,000 Btu; mbtu = 1 million Btu

Coefficient of Performance (COP): For cooling, it is the ratio of the rate of net heat removal to the rate of total energy input, calculated under designated operating conditions and expressed in consistent units, as determined using the applicable test method in the Appliance Efficiency Regulations. For heating, it is the ratio of the rate of net heat output to the rate of total energy input, calculated under designated operating conditions and expressed in consistent units, as determined using the applicable test method in the Appliance Efficiency Regulations.

Cooling Tower Institute (CTI): This organization establishes test specifications for cooling towers.

Direct Digital Control (DDC): These are microprocessor-based controls that can perform a number of functions, such as supply air temperature reset, optimal fan start, and supply air pressure reset.

Direct Expansion Unit (DX): Any system that, in operation between an environment where heat is absorbed (heat source), and an environment into which unwanted heat is directed (heat sink) at two different temperatures, is able to absorb heat from the heat source at the lower temperature and reject heat to the heat sink at the higher temperature. The cooling effect is obtained directly from a fluid called a refrigerant that absorbs heat at a low temperature and pressure, and transfers heat at a higher temperature and higher pressure.

Effective Apperture (EA): This is the product of the window wall ratio (WWR) multiplied by the visible light transmittance (VLT). When the EA is greater than 0.18, daylighting saturation will be achieved.

Efficacy: The ratio of light from a lamp to the electrical power consumed (including ballast losses) expressed in lumens per watt.

Energy Conservation Opportunities (ECOs): This is a measure that when implemented will result in reduced energy use for the facility. An ECOs can also be known as an energy efficiency opportunity.

Energy Efficiency Opportunity (EEOs): This is the same as an ECOs.

Energy Efficiency Ratio (EER): This is the ratio of net cooling capacity (in BTU/hr) to total rate of electrical energy (in watts), of a cooling system under designated operating conditions, as determined using the applicable test method in the Appliance Efficiency Regulations.

Energy Star: A US EPA program that provides information on high efficiency appliances, heating and cooling equipment, windows, lighting, water coolers, office equipment, roof products, transformers, water coolers traffic lights and other energy using equipment.

Exterior Insulation Finish Systems (EIFS): This is an exterior masonry insulation that provides a continuous insulating barrier for masonry walls.

Heating, Ventilating and Air Conditioning (HVAC): A system that provides heating, ventilation and/or cooling within or associated with a building.

High Albedo: A surface capable of reflecting the majority of the solar heat that strikes it. Having a high reflectance means a material reflects the majority of solar heat. A reflectance of 0.75 or greater is desireable.

High Intensity Discharge (HID): This is a type of lamp that has a long relighting time.

Horsepower (HP): A unit for measuring the rate of doing work. One horsepower equals about three-fourths of a kilowatt (745.7 watts).

Illuminating Engineer Society (IES): This organization is the technical authority on illumination and provides information on all aspects of good lighting practice.

Integrated Part Load Value (IPLV): This is a single-number figure of merit based on part load EER or COP expressing part load efficiency for air conditioning and heat pump equipment on the basis of weighted operation at various load capacities for the equipment as determined using the applicable test method in the Appliance Efficiency Regulations.

Life Cycle Cost (LCC): Amount of money necessary to own, operate and maintain a piece of equipment over its useful life

Lighting Power Density (LPD): The LPD is measured in terms of watts per square feet.

Luminaire: This is a complete lighting unit consisting of a lamp and the parts designed to distribute the light, to position and protect the lamp, and to connect the lamp to the power supply; commonly referred to as a light fixture.

Projection Factor (PF): This is the ratio of projection of the overhang to the distance from the bottom of the window to the bottom of the overhang. The larger the PF the larger the overhang.

Seasonal Energy Efficiency Ratio (SEER): This is the total cooling output of a central air conditioner in BTU during its normal usage period for cooling divided by the total electrical energy input in watt-hours during the same period, as determined using the applicable test method in the Appliance Efficiency Regulations.

Solar Heat Gain Coefficient (SHGC): This coefficient describes the fraction of solar heat gain that is transmitted through various glazing. Clear class has an SHGC of about 0.86 while reflective glass has an SHGC of less than 0.35.

Thermal Energy Storage (TES): These systems are used to store energy generated during electric utility off-peak hours for use during the on-peak and/or partial peak periods.

Thermal Resistance (R-Value): This is the resistance of a material or building component to the passage of heat in (hr x ft^2 x ^{o}F)/Btu.

Title 24 Building Energy Efficiency Standards: These standards for residential and nonresidential buildings are mandatory and apply to the design and construction of all new private and public buildings in California.

U-Value: This is the overall coefficient of thermal resistance of a construction assembly, in Btu/(hr x ft^2 x ^{o}F), including air film resistance at both surfaces.

Variable Air Volume (VAV): This is a space conditioning system that maintains comfort levels by varying the volume of conditioned air to the zones served.

Variable Frequency Drive (VFD): This unit regulates motor speed based on specified operating conditions (e.g., air and water temperature).

Visible Light Transmittance (VLT): A term used in glazing to indicate the relative amount of daylighting that will enter the space.

Window Wall Ratio (WWR): This is the ratio of the window area to the gross exterior wall area.

- For information on how the Energy Commission's Energy Efficiency Programs can help reduce energy cost in your facilities, contact:

  California Energy Commission
  Nonresidential Buildings Office
  1516 Ninth Street, MS-26
  Sacramento, CA 95814

  Telephone: (916) 654-4008
  FAX: (916) 654-4304

  Web Site: www.energy.ca.gov/efficiency

- For information on detention facilities construction grant funding, security, fire and life safety plan review, contact:

  California Board of Corrections
  600 Bercut Drive
  Sacramento, CA 95814

  Telephone: (916) 445-5073
  FAX: (916) 445-5796

  Web Site: www.bdcorr.ca.gov